# STRUCTURAL REANALYSIS SYSTEM (SRS) FOR THE PHILLIPS PETROLEUM GROUP'S "MAUREEN" TSG PLATFORM USING MSC/NASTRAN SUPERELEMENT DATA BANK AND DMAP PROCESSING

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## ABSTRACT

The Maureen Platform Structural Reanalysis System (SRS), based on MSC/NASTRAN Superelement Data Bank and DMAP processing, provides a rapid and low cost computer analysis of structural integrity in the event of damage to primary steel works.

This paper describes the main components of the system and how it is used in case of structural damage.

The system is composed of:

- the "as built" MSC/NASTRAN structural model of the platform (24,000 DOFs subdivided into 5 superelements)
- the structural Data Bank, including all the input/output data relevant to the NASTRAN analyses performed on the intact structure
- a set of DMAP routines to manage the Data Bank and interactive software devoted to quick selection, sorting and visualization of data included in the Data Bank
- a set of operating manuals to guide the structural reanalysis.

The actions to be performed by the SRS in case of damage are:

- automatic identification of the structural area sensitive to the damage (critical area)
- automatic identification of the loading conditions from 200 combined loading cases that induce the maximum stresses in the elements of the critical area
- automatic generation of a reduced structural model (i.e. damage model) in NASTRAN format, including load vectors for the critical loading conditions and relevant boundary conditions for the reduced model
- structural reanalysis and checks of the elements in the reduced model
- visualization on a graphic screen of the required parameters (displacements, forces, safety factors, etc.) for each desired portion of the structure.

A team of engineers and computer scientists then analyze the results and reach conclusions regarding the structural integrity of the platform.

The SRS System allows all these operations to be performed in less than 24 hours, a process which in the past has taken weeks, even months to be performed.

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## 1. PREMISES AND INTRODUCTION

The probability of structural damage to an offshore platform is high enough to require emergency assessment procedures to be established for the operative life of a particular facility. As operator for the Maureen field, Phillips Petroleum Company United Kingdom Ltd.'s main requirements for establishing their emergency procedures were to obtain a rapid and reliable response regarding structural integrity in the event of damage to primary steel works of the Maureen platform, located in the North Sea.
The very high costs relevant to production loss and the safety aspects associated with more than 100 offshore personnel were significant in developing a system satisfying these requirements. Furthermore, it was clear that sophisticated analysis procedures would be required due to the complexity of the model and the great number of loading conditions to be considered.
To meet Phillips Petroleum's requirements, a completely integrated procedure based on MSC/NASTRAN facilities was developed by Tecnomare, containing the results of several structural analyses carried out on the platform in non-damaged conditions. Interactive software allows a quick selection of the data stored in the data bank, followed by reanalysis of the structure in a very short time to assess the influence of the damage on the structural safety of the platform.
The MSC/NASTRAN has been used as the basis of the entire system, due to its efficiency and reliability and to its flexibility to link, in an integrated procedure, DMAP language and Tecnomare pre- and post-processors.

## 2. DESCRIPTION OF THE PLATFORM, SRS AND EMERGENCY SERVICE

### 2.1 The Maureen Structure

The Maureen platform is a steel gravity platform designed by Tecnomare between 1978 and 1982. The installation of the platform in the Maureen field, at 95.6 m water depth, was performed in 1983. The structure is the largest steel platform (42,000 tons in the substructure and 27,000 tons in the deck in operating configuration) ever built in the North Sea.
The platform (Fig. 2.1) is based on a tripod, all-steel, gravity structure concept. Three cylinders provide buoyancy and stability during transportation and installation, and oil storage capacity during the operating life. A framed structure connects the main components and supports the upper deck with the equipment.

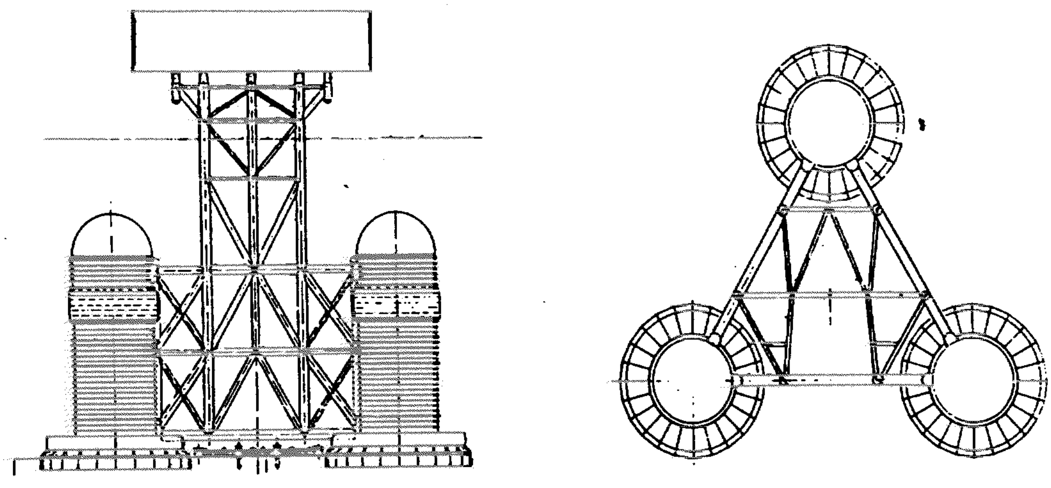


Fig. 2.1

The platform has been designed to withstand, with different safety factors, the following conditions:

| | 50 YEAR CONDITION | OPERATING CONDITION | 3 YEAR CONDITION |
|---|---|---|---|
| Wave height (m) | 27 | 18 | 23 |
| Wave periods (m) | 13.5 17.0 | 11.0 16.5 | 12.4 17.0 |
| Wind speed (m/sec) | 48 | 34 | 41.8 |
| Current speed (m/sec): | | | |
| . surface | 1.25 | 0.88 | 1.09 |
| . bottom | 0.24 | 0.18 | 0.21 |

## 2.2 Description of the SRS

The system is composed of:

a) An MSC/NASTRAN structural data bank, which includes (see also Fig. 2.2):
   - the MSC/NASTRAN "as-built" structural model of the platform (24,000 DOFs subdivided into five superelements),
   - all the MSC/NASTRAN results relevant to a large number of structural analyses carried out on the structure in intact conditions,
   - all the safety factors generated by the structural checks carried out on the structural members for the intact structure.

b) A set of computer programs and DMAP routines to generate and manage the data bank, as well as interface with the Tecnomare structural check programs.

c) Interactive software, which allows (see Fig. 2.3):
   - a quick access to the content of the data bank,
   - an assessment of the structure in the area of interest by the analysis and sorting of any structural parameter (internal forces, safety factors, displacements, load vectors, etc.),
   - the automatic generation of a reduced structural model and relevant boundary conditions to allow the reanalysis of the damaged area only,
   - the visualization, on graphic screen, of the desired parameter, read from the data bank and shown on the desired portion of the structure.

d) A set of operating manuals to guide the structural reanalysis. These contain all the operating procedures for:
   . the utilisation of the system,
   . the criteria for damage evaluation,
   . the actions to be undertaken.

Fig. 2.2

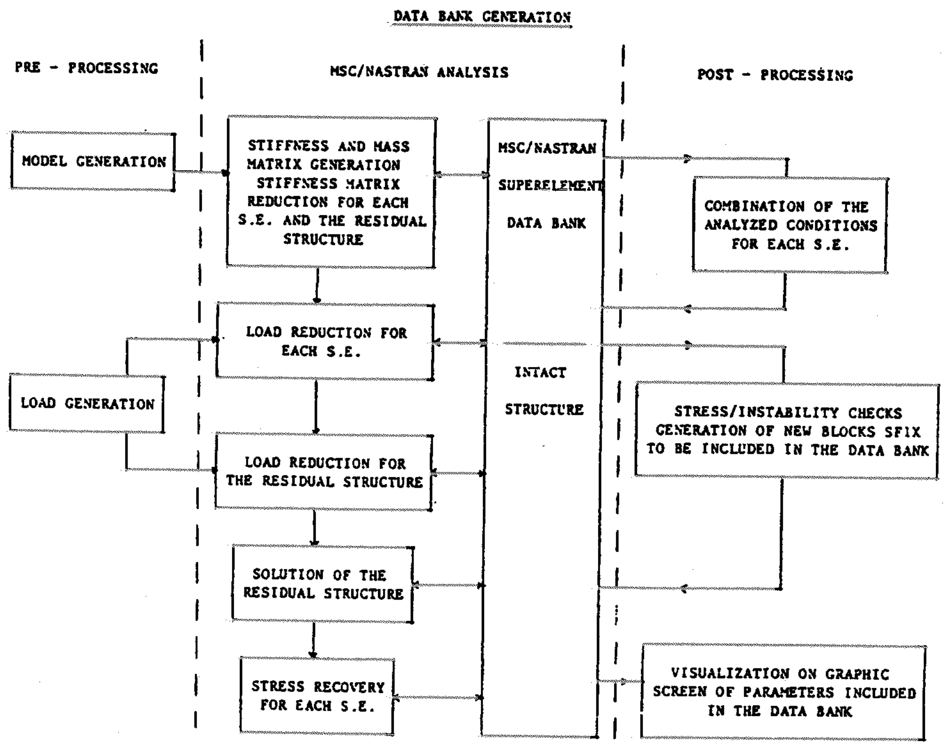
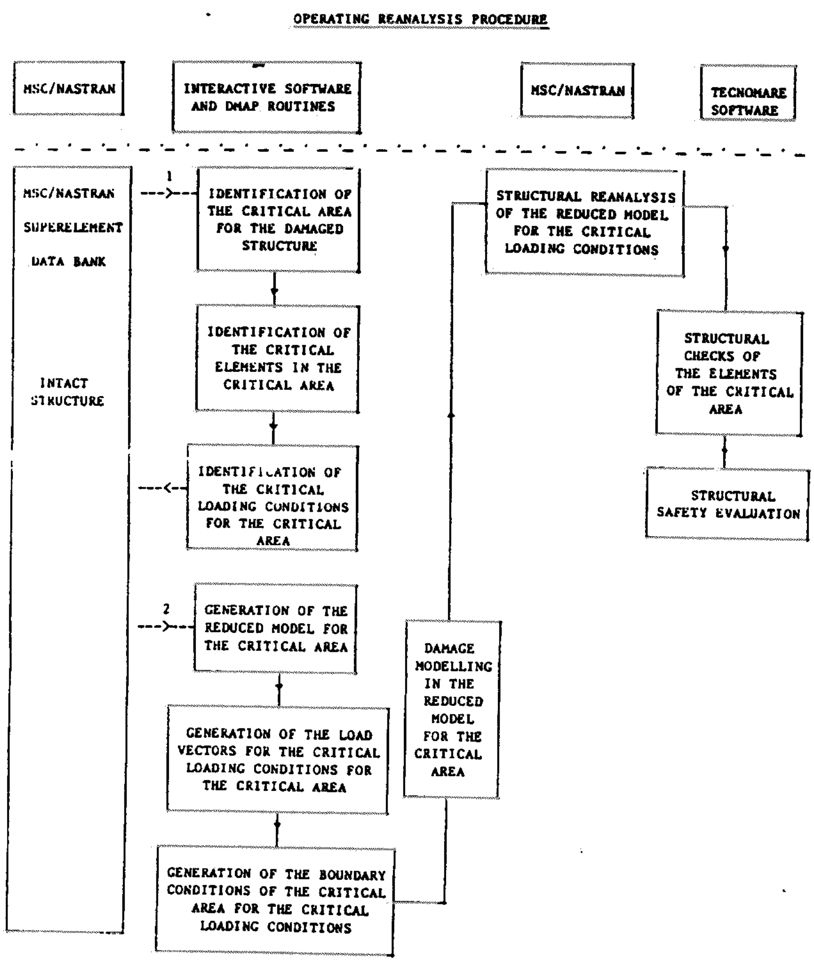

DATA BANK GENERATION
PRE - PROCESSING
MSC/NASTRAN ANALYSIS
POST - PROCESSING
MODEL GENERATION
STIFFNESS AND MASS MATRIX GENERATION STIFFNESS MATRIX REDUCTION FOR EACH S.E. AND THE RESIDUAL STRUCTURE
MSC/NASTRAN SUPERELEMENT DATA BANK
COMBINATION OF THE ANALYZED CONDITIONS FOR EACH S.E.
LOAD REDUCTION FOR EACH S.E.
INTACT STRUCTURE
LOAD GENERATION
STRESS/INSTABILITY CHECKS GENERATION OF NEW BLOCKS SFIX TO BE INCLUDED IN THE DATA BANK
LOAD REDUCTION FOR THE RESIDUAL STRUCTURE
SOLUTION OF THE RESIDUAL STRUCTURE
STRESS RECOVERY FOR EACH S.E.
VISUALIZATION ON GRAPHIC SCREEN OF PARAMETERS INCLUDED IN THE DATA BANK

Fig. 2.3


OPERATING REANALYSIS PROCEDURE
MSC/NASTRAN
INTERACTIVE SOFTWARE AND DMAP ROUTINES
MSC/NASTRAN
TECNOMARE SOFTWARE
MSC/NASTRAN SUPERELEMENT DATA BANK
INTACT STRUCTURE
1
IDENTIFICATION OF THE CRITICAL AREA FOR THE DAMAGED STRUCTURE
STRUCTURAL REANALYSIS OF THE REDUCED MODEL FOR THE CRITICAL LOADING CONDITIONS
IDENTIFICATION OF THE CRITICAL ELEMENTS IN THE CRITICAL AREA
STRUCTURAL CHECKS OF THE ELEMENTS OF THE CRITICAL AREA
IDENTIFICATION OF THE CRITICAL LOADING CONDITIONS FOR THE CRITICAL AREA
STRUCTURAL SAFETY EVALUATION
2
GENERATION OF THE REDUCED MODEL FOR THE CRITICAL AREA
DAMAGE MODELLING IN THE REDUCED MODEL FOR THE CRITICAL AREA
GENERATION OF THE LOAD VECTORS FOR THE CRITICAL LOADING CONDITIONS FOR THE CRITICAL AREA
GENERATION OF THE BOUNDARY CONDITIONS OF THE CRITICAL AREA FOR THE CRITICAL LOADING CONDITIONS

Note

The three bases/cylinders and the framed structure of the Maureen platform have been separately considered in environmental load generation, because the different dimensions of the structural elements with respect to the length of the incident wave call for the use of different theories to calculate the wave loads.

| | TECNOMARE MSC/NASTRAN PRE-PROCESSOR | THEORY |
|---|---|---|
| FRAMED STRUCTURE<br>Ø ≤ 3.5 m | CARGON 3 | - Stokes 5th order wave theory<br>- Non-linear wave loads using the Morison's equations |
| CYLINDERS AND BASES<br>Ø > 24 m | CARDIF<br><br>BESFIT | - Airy wave theory<br>- Linear wave inertia pressures using the 3D diffraction theory<br><br>- Non-linear drag effects accounted for as phase shift on linear wave pressures |

## 2.3 Description of the Emergency Service

To ensure a very high reliability of the SRS, Tecnomare was requested by Phillips Petroleum to supply an emergency service. In the event of damage, the main objectives of the service are:

- to provide a quick mobilization of the necessary personnel,
- to provide a quick response (within 24 hours) regarding the structural safety of the damaged platform,
- to update the system data bank and software, if required,
- to organize the training of the personnel devoted to the service and to perform periodical tests of the procedure,
- to collect and analyze data recorded on board by the platform structural monitoring system, as required.

## 3. STRUCTURAL MODELLING

### 3.1 Generalities and Superelement Partitioning

The main reasons that led to the decision to utilize MSC/NASTRAN Superelement Capability in order to make the analysis consistent with an optimized use of Tecnomare in-house computer SPERRY 1100/70 are:

- the dimensions of the numerical problems to be solved - the model contains approximately 24000 DOFS,
- the number of loading conditions to be analyzed - 131 - and the different wave theories to be used in generating environmental loads on the different components of the platform,
- considerations on the application of the complete procedure to single superelements,
- the efficiency and flexibility of the MSC/NASTRAN Superelement data bank.

The partitioning has been performed to obtain an efficient and logical subdivision of the main parts of the structure taking into account the above reasons, mainly the applications of different pre-processors and post-processors to generate loads and to check the structural members of the different superelements.
A single level superelement subdivision has been adopted; five superelements have been generated (Figs. 3.1 - 3.2):

- 3 cylinders
- framed structure
- deck.

Fig. 3.1

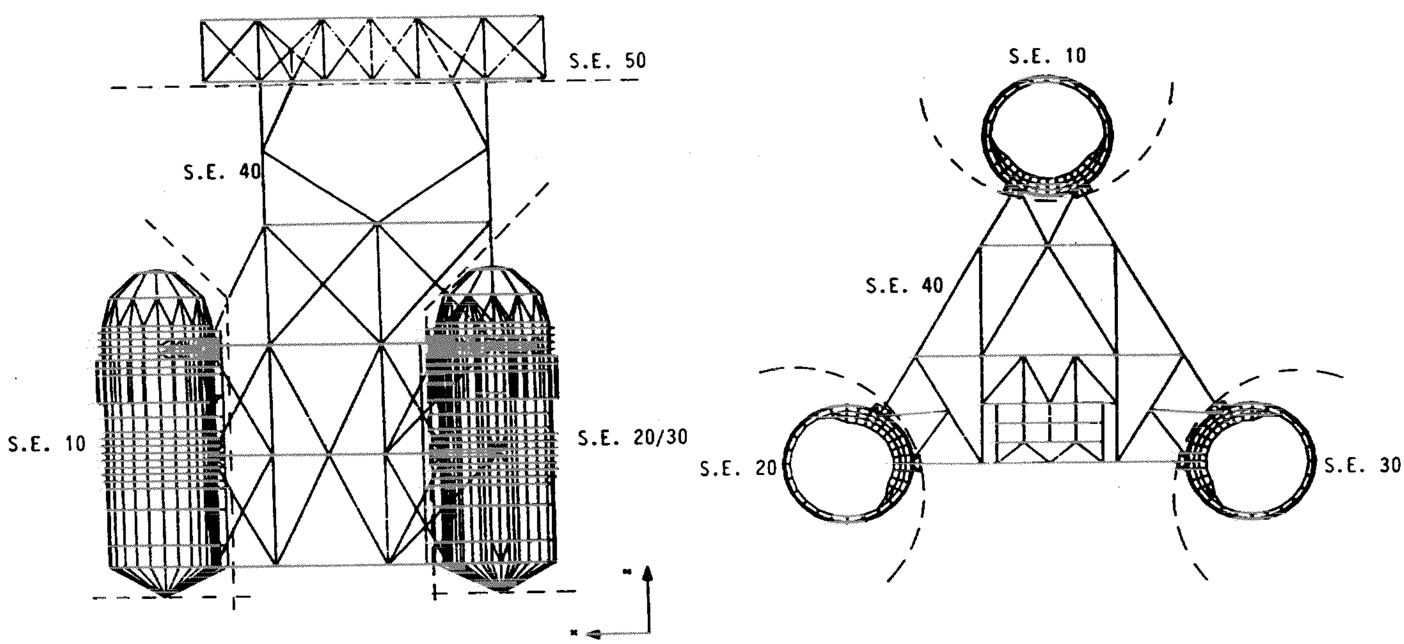
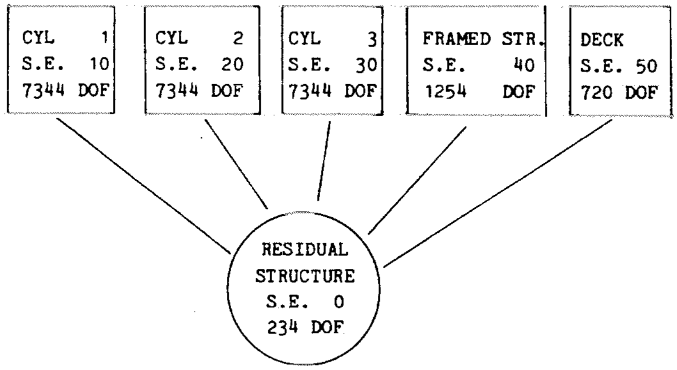


Fig. 3.2



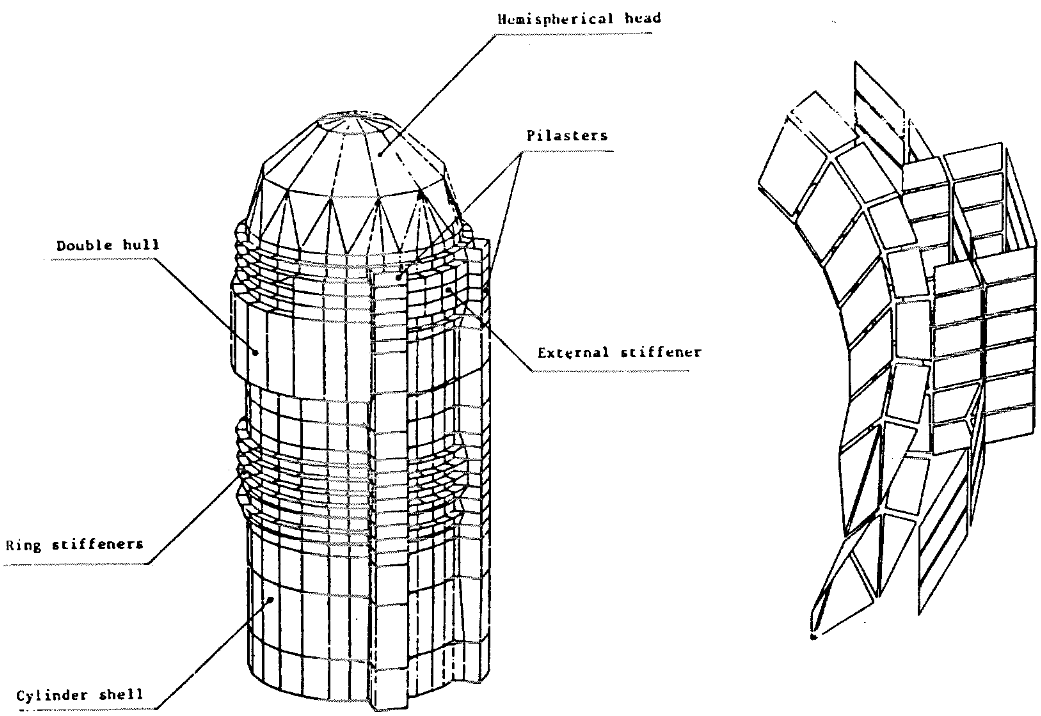

The three cylinders were fully generated as different superelements instead of considering (as per the design phase) only one superelement composed of half a cylinder and symmetry and repetition to complete the model.
This was due to the need to operate on the model and stiffness matrices of the single cylinder, in the event of damage, leaving the others intact, and to update in this way the data bank.

## 3.2 Structural Modelling

### Cylinders and bases

The cylinder shells, cupolas, pilasters, the internal stiffener and the ring stiffener webs have been modelled using quadrilateral (QUAD4) and triangular (TRIA3) plate elements, while BAR elements have been used to model ring stiffener flanges.

Fig. 3.3

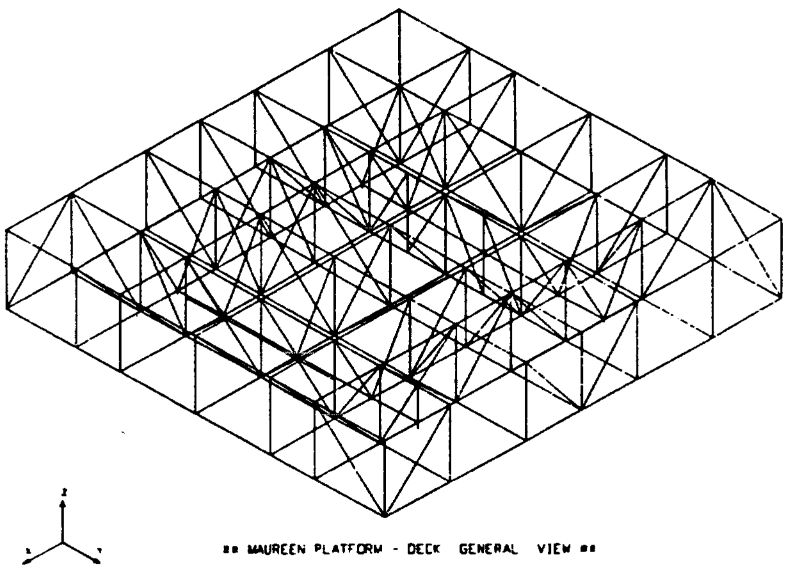


Each cylinder, defined in a local cylindrical coordinate system, is supported by a base standing on the seabed soil. The soil stiffness is represented by a set of six soil springs at the underside of each base.
The bases are represented as rigid body elements (RBE2) connecting the springs to the cylinders.
There are two reasons for this assumption:

- the structural behaviour of the bases is of minor importance for the scopes of the present analysis;
- the stiffness of the springs is derived from the elaboration of data collected by the instrumentation of the structural monitoring system positioned at the top of each base, thus including the base stiffness in the derivation of soil parameters.

Deck
The main structure (Fig. 3.4) has been modelled using BAR elements, while equivalent membrane elements have been used to represent the in-plane membrane stiffness of the secondary structure of the deck levels.
The deck superelement has been utilized also as a separate structure to compute deformation forces induced during its installation over the substructure.

Fig. 3.4




Framed structure
The whole structure, composed of tubular members, has been modelled using longitudinal BAR elements.
All the non-structural elements (i.e. conductors, piping, etc.) have been represented in the pre-processing model to account for their contribution in environmental load generation.

The interface between the bar elements of the framed structure and the plate elements of the cylinders has been modelled using rigid body elements RBE2 connecting each boundary node of the framed structure with eight nodes of the pilaster surface.

## 4. DATA FLOW

### 4.1 Geometric Data Generation

Certain NASTRAN input decks were available from analyses carried out during the design phase. A new software package was developed to read the old input decks and generate new input decks relevant to the actual configuration of the structure.

| SUPER ELEMENT | IMPLEMENTATION MODE | No. OF ELEMENTS | No. OF NODES | REFERENCE SYSTEM |
|---|---|---|---|---|
| DECK | A standard graphic program was used to generate the model of the deck structure not available from previous analyses. | 428 | 120 | Global |
| FRAMED STRUCTURE | The model of the framed structure was available from previous analyses. | 517 | 209 | Global |
| CYLINDERS AND BASES | The model of half a cylinder was available from previous analyses. Ad-hoc software has been written in order to obtain the complete input meshes of all three cylinders and to be able to extend any correction made on the half cylinder to all six half cylinders (see fig. 4.1). | 1888 x 3 | 1224 x 3 | Cylindrical local |
| RESIDUAL STRUCTURE | Only the interface nodes between the superelements and the 3 base nodes are included in the R.S. (Residual Structure). | 3 | 39 | Global |

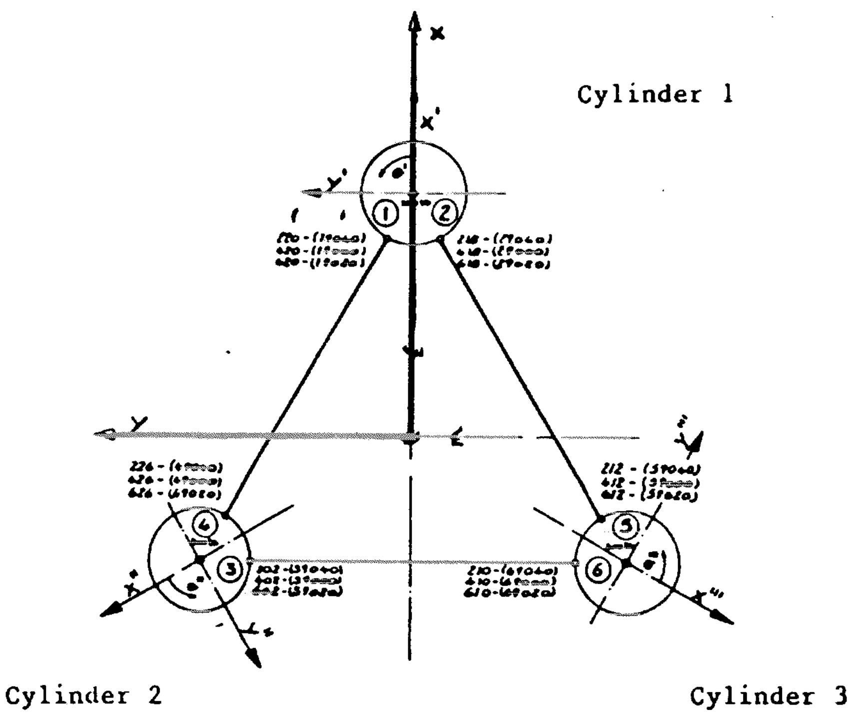



Fig. 4.1

## 4.2 Load Data Generation

### 4.2.1 Environmental Loads

An automatic generation of environmental loads was performed, using Tecnomare programs utilized as NASTRAN preprocessors, as described in the following table.

| S.E. | LOAD DESCRIPTION | No. of LOADING CONDITIONS | REFERENCE SYSTEM |
|---|---|---|---|
| DECK | The CARGON3 program has been used to generate loads due to wind directly as NASTRAN FORCE input cards.<br>The following conditions have been considered:<br>- operative storm wind : 5 headings<br>- 50 year storm wind : 5 headings<br>- 3 year storm wind : 5 headings | 15 | Global |
| FRAMED STRUCTURE | The CARGON3 program has been used to study wave and current loads on the framed structure.<br>NASTRAN FORCE, MOMENT and PLOAD1 cards have been generated for the conditions reported herebelow:<br>. 5 headings<br>. 4 positions along the wave length (the ones giving the max. global forces on the structure)<br>. 2 wave periods for each of the 3 analyzed sea states. | 120 | Global |
| 1 CYLINDER + 1 BASE (phase 1) | The program CARDIF has been used to generate the wave and current pressures on the F.E. of half a cylinder and base, and to expand them by symmetry to the whole cylinder and relevant base. The following conditions have been considered:<br>. 5 headings<br>. 2 positions along the wave length (crest and trough)<br>. 2 wave periods for each of the 3 analyzed sea states. | 60 | Cylindrical local |
| RESIDUAL STRUCTURE | The forces generated for the above superelements and acting on the interface nodes have been considered acting directly on the residual structure. | 120 | Global |
| CYLINDERS (phase 2) | The program CYPREX has been used for the expansion and phasing of the pressures evaluated for one cylinder to the complete set of three cylinders taking into account their relative position with respect to the axes of the structure (see fig. 4.1).<br><br>PLOAD2 NASTRAN pressure cards relevant to the considered loading conditions have been generated | 60 | Cylindrical local |
| BASES (phase 2) | Due to the simplified modelling of the bases, the relevant pressures have been integrated on the base surfaces and applied as a single force. | 60 | Cylindrical local |

### 4.2.2 Permanent, Live and Deformation Loads

As well as the environmental loads previously described, the following loading conditions have been considered:

| S.E. | LOAD DESCRIPTION | No. of LOADING CONDITIONS | REFERENCE SYSTEM |
|---|---|---|---|
| DECK | . Dead and live loads<br>. Deformation loads due to the loading history of the deck | 4 | Global |
| FRAMED STRUCTURE | . Dead weight and buoyancy forces | 1 | Global |
| CYLINDERS AND BASES | . Dead weight and buoyancy forces<br>. Hydrostatic operating differential pressure | 2 | Cylindrical local |
| BASES | . Unit rotations of the bases around the two horizontal global axes to be used as deformation loading conditions | 6 | Cylindrical local |
| RESIDUAL STRUCTURE | . Dead weight and buoyancy forces | 1 | Global |
| N.B. - Deformation loading conditions and hydrostatic pressures on the cylinders have been considered as global conditions with the loads acting only on the relevant S.E. | | | |

### 4.3 NASTRAN Data Bank Generation

The input data for the whole analysis have been recorded in the NASTRAN data base DB01 using the static solution SOL 62 and checked against possible errors.
An extensive set of tests has been carried out to check the model:

- visual mesh checks using videographic tools,
- superelement compatibility checks using NASTRAN standard SOL 60,
- solution with elementary loading conditions to be compared with theoretical results,
- comparison of typical results with the ones obtained during the design phase to check their congruence.

The combination of elementary load sets to generate the load vectors for the single superelements and the assembling of global basic loading conditions are reported in Fig. 4.2.

Fig. 4.2

| | EQUIVALENT GLOBAL LOAD CASE NUMBERS 1 --> 120 | | | EQUIVALENT GLOBAL LOAD CASE NUMBERS 121 --> 122 | | | EQUIVALENT GLOBAL LOAD CASE NUMBERS 123 --> 125<br>126 --> 131 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENVIRONMENTAL PERMANENT AND LIVE LOADS | | | PERMANENT AND LIVE LOADS | | | LOAD HYSTORY AND BASE ROTATIONS | | | DUMMY CONDITIONS | | | |
| | FRAMED STRUCTURE & DECK (S.E. 40,50) | CYLINDERS (S.E. 10, 20, 30) | RESIDUAL STRUCTURE (S.E.0) | F&D | C. | R.S. | F&D | C. | R.S. | F&D | C. | R.S. | |
| ELEMENTARY CONDITIONS FOR SINGLE S.E. | DO<br>01:0120<br>V1:V15 | C1:C60<br>C62<br>C63 | ZAVO<br>01:0120 | 0121<br>DO | C62<br>C63 | ZAVO<br>0121 | LH1<br>LH2<br>LH3 | - | BR1:<br>BR6 | DJ<br>DD | C61 | - | LEVEL 1 |
| LOAD VECTORS FOR SINGLE S.E. | JD1:<br>JD120 | C1:C60<br>C62<br>C63 | 01*:0120* | JD121 | C62+<br>C63<br>C63 | 0121* | LH1<br>LH2<br>LH3 | - | BR1:<br>BR6 | JD122 | C61 | - | LEVEL 2 |
| REDUCED L.C. ON THE RESIDUAL STRUCTURE | JD1:<br>JD120<br>(A) | 1*:120*<br>(A) | 01*:0120*<br>(B) | JD121<br>(A) | 121*<br>C63<br>(A) | 0121*<br>(B) | LH1<br>LH2<br>LH3<br>(A) | - | BR1:<br>BR6<br>(B) | JD122<br>(A) | C61<br>(A) | - | LEVEL 3 |

Combination of Basic Load Cases

Notes: A- These load cases are reduced to those acting on the grid points associated with the residual structure.
B- These load cases apply directly to grid points within the residual structure.

Summary Table of Global Loading Conditions

DD - DJ — Dummy conditions for the deck and the framed structure

JD1 - JD120 — Composed load vectors on framed structure and deck. (Consists of relevant combinations of 01-120 plus DO plus V1-V15).

JD121 — Null wave, weight and buoyancy, deck loads

JD122 — Dummy load

ZAVO — Gravity load on the residual structure (solid ballasting on the bases)

LH1 - LH3 — Load history cases

BR1 - BR6 — Base rotations

C1 - C60 — CARDIF/CYPREX outputs: Hydrodynamic loads on cylinders at 0° (crest) and 90° (trough) along the wave length for each condition

C61 — Dummy condition for the cylinders

C62 — Null wave, cylinders weight and buoyancy

C63 — Hydrostatic pressure on the cylinders

1* - 120* — Linear combination of the reduced load vectors

121* — C62 + C63 reduced on the residual structure

| GLOBAL LOAD CASES | NASTRAN LOAD CASES | BASIC LOAD CASES | | | |
|---|---|---|---|---|---|
| | | FRAMED S. AND DECK | CYLINDERS | RESIDUAL STRUCTURE | NOTES |
| 1<br>⟆<br>120 | 10110<br>⟆<br>50360<br>(A) | JD1<br>⟆<br>JD120 | 1*<br>⟆<br>120* | 01*<br>⟆<br>0120* | PERMANENT, LIVE AND ENVIRONMENTAL CONDITIONS (ALL WITH LOAD FACTOR = 1) |
| 121 | 90001 | JD121 | 121* | 0121* | PERMANENT AND LIVE CONDITIONS |
| 122 | 90003 | JD122 | C63 | - | ONLY HYDROSTATIC PRESSURE ON THE CYLINDERS |
| 123 | 70002 | LH1 | - | - | DECK ON BARGE CONDITION APPLIED TO THE DECK ONLY |
| 124 | 70003 | LH1-LH3 | - | - | DECK INSTALLATION + JACKING FORCES (WITHOUT KNEE BRACES) |
| 125 | 70004 | LH1-JD122 | C61 | - | AFTER MATING (WITH KNEE BRACES) |
| 126<br>⟆<br>131 | 60001<br>⟆<br>60006 | JD122<br>⟆<br>JD122 | C61<br>⟆<br>C61 | BR1<br>⟆<br>BR6 | UNITARY BASE ROTATIONS |

NOTES: (A) = 1 0 1 1 0

Heading (1 to 5)
Wave h. (1 to 3)
Step (1,2,5,6)

### 4.4 Static Solution

The complete solution procedure is reported in the following sketch.
The output data generated by the stress recovery have been stored in the Data Base DB02.

Fig. 4.3

| PHASE | NASTRAN SOLUTION | DESCRIPTION | CPU (SEC) SPERRY 1100/70 | OUTPUT DB |
|---|---|---|---|---|
| MASS AND STIFFNESS MATRICES REDUCTION | SOL 62 | Mass and stiffness matrices have been generated and reduced for:<br>- deck<br>- jacket<br>- cylinders | <br><br>1500<br>1700<br>36900 | DB01 |
| LOAD VECTORS REDUCTION | SOL 62 | Load vectors have been reduced for:<br>- deck (120+11 loading conditions)<br>- jacket (120+11 loading conditions)<br>- cylinders (60+11 loading condit.) | } 19800<br><br>26300 | DB01 |
| | TECNOMARE DMAP PROGRAM | Due to the linearity of the wave loads acting on the cylinders, to make the 60 reduced load vectors of the cylinders consistent with the 120 acting on the other S.E.s, a sinusoidal variation of the force with time has been assumed (DMAP program LINCOL - phase 1) following the law:<br>$[f(t)] = [f_1] \cos wt + [f_2] \sin wt$<br>where:<br>. $[f_1]$ and $[f_2]$ are the reduced load vectors on the wave crest and trough position<br>. w is the circular wave frequency<br>. t is the time | 6100 | DB01 |
| RESIDUAL STRUCTURE SOLUTION | SOL 62 | The residual structure has been solved for 120+11 loading conditions | 37600 | DB01<br>DB02 |
| STRESS RECOVERY | SOL 62 | The Stress Recovery has been accomplished for:<br>- deck (120+11 loading conditions)<br>- jacket (120+11 loading conditions) | } 21100 | DB02 |
| | TECNOMARE DMAP PROGRAM | To save computer time, the stress recovery for the cylinders has been performed only for the condition the cylinders had to be checked for.<br>From the results on the R.S. the most severe loading conditions for the cylinders were chosen.<br>The complete load vectors on the cylinders were combined only for the selected loading conditions as previously described for the reduced load vectors (DMAP program LINCOL - phase 2). | 7500 | DB01 |
| | SOL 62 | The Stress Recovery has been performed for:<br>- cylinders (30+11 loading conditions each) | 18900 | DB02 |

## 4.5 Load, Displacement and Element Forces Combination

The DMAP program COMB has been written in order to allow linear combinations on the 131 elementary loading conditions. In particular:

a) standard DMAP statements have been used to combine the blocks:
   - OPG1 - Load vectors
   - OUGV1 - Nodal displacements
   - OQG1 - Forces on single point constraints.

b) a Tecnomare FORTRAN code, inserted in LINK7 NASTRAN program and available for use by means of the MODA DMAP module, has been used to combine the block:
   - OEF1X - Element forces.

The following table shows how the conditions relevant to permanent, live and deformation loads have been combined with the ones relevant to environmental loads to produce the conditions for the checks required by the different codes. Deformation loads include the load history of the deck and a linear combination of unit base rotations based on results obtained from the monitoring system.

Fig. 4.4

FRAMED STRUCTURE AND DECK (second qual. 40 and 50 respectively)

| CONDITIONS | Environmental + permanent and live (1 ÷ 120) | | Deformation | | Combined loading conditions |
|---|---|---|---|---|---|
| | Coefficient | Loading conditions | Coefficient | Loading conditions | |
| W1<br>1 month storm | 1. | 1 ---> 40 | 1. | 9 | 1 ---> 40 |
| W2<br>3 year storm | 1. | 41 ---> 80 | 1. | 9 | 41 ---> 80 |
| W3<br>50 year storm | 1. | 81 ---> 120 | 1. | 9 | 81 ---> 120 |

CYLINDERS (Second qualifier 10, 20, 30 respectively)

| CONDITIONS | Environmental + permanent and live | | Permanent and live | | Deformation | | Combined loading conditions |
|---|---|---|---|---|---|---|---|
| | Coefficient | Loading conditions | Coefficient | Loading conditions | Coefficient | Loading conditions | |
| W1<br>1 month storm | 0.7 | 1 ---> 10 | 0.6 | 2 | 1. | 9 | 1 ---> 20 |
| | 1.3 | 1 ---> 10 | -0.3 | 2 | 1. | 9 | |
| W2<br>3 year storm | 0.7 | 11 ---> 20 | 0.6 | 2 | 1. | 9 | 21 ---> 40 |
| | 1.3 | 11 ---> 20 | -0.3 | 2 | 1. | 9 | |
| | 1. | 11 ---> 20 | / | 2 | 1. | 9 | 41 ---> 50 |
| W3<br>50 year storm | 0.7 | 21 ---> 30 | 0.6 | 2 | 1. | 9 | 51 ---> 70 |
| | 1.3 | 21 ---> 30 | -0.3 | 2 | 1. | 9 | |

### 4.6 Structural Checks

The checks have been performed by Tecnomare check programs (NASTRAN post-processors) reading combined loading conditions and following the procedure described below:

| No. | DESCRIPTION | OUTPUT FILE |
|---|---|---|
| 1 | A DMAP program has been used to read from the data base DB02 the block OEF1X (element forces) and to store it in a FORTRAN readable file UT1. | UT1 |
| 2 | Tecnomare programs were used to check all the Superelements:<br>- deck : NAISC4 program<br>Stress instability check of non-tubular members following API RP 2A - AISC codes<br>- framed structure: NAISC3 + PUNSHE programs<br>Stress instability check of tubular members following API RP 2A - AISC codes<br>Punching shear checks of tubular nodes following DNV code.<br>- cylinders : DNV77 program<br>Stress instability checks of plane and cylindrical panels following DNV code.<br><br>The results have been included in blocks (SF1X) similar to the OEF1X and written into a FORTRAN file UT2 readable by NASTRAN | UT2 |
| 3 | A DMAP program has been used to read the FORTRAN file UT2 and store the blocks into the data base DB02. | DB02 |

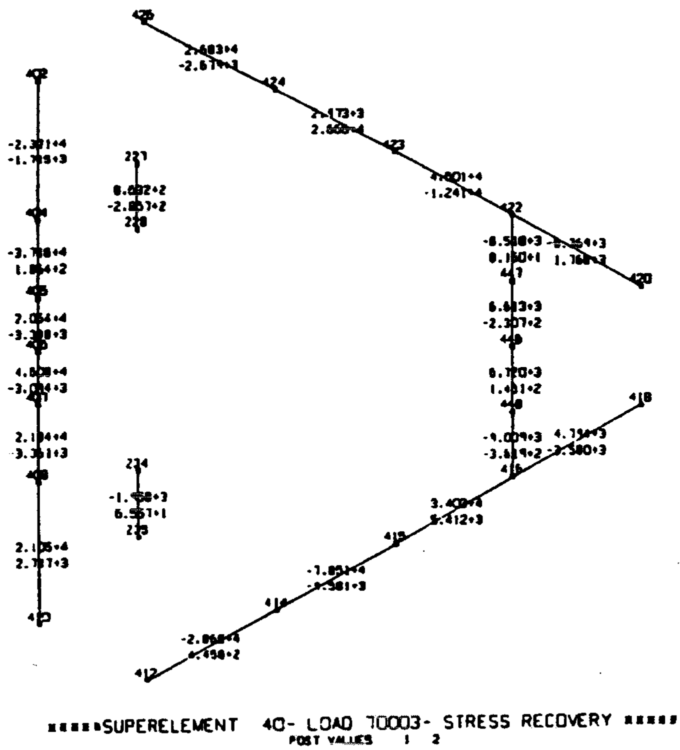
### 4.7 Graphic Visualization of the Results

A graphic NASTRAN input pre-processor (data introduction) and output post-processor (data visualization), has been implemented by:

- capability to read NASTRAN user tape UT1
- capability to display data read from a block in a file UT1 in the geometric centre of the corresponding finite element.

In this way, the immediate graphic visualization of any value stored in the data base DB02 (displacements, loads, element forces, safety factors, etc.) is possible.
A typical example is shown in Fig. 4.5.

Fig.4.5




(Bending moments at first end)

## 4.8 Data Base Contents

The data base content together with the storage space needs in the disk is summarized in the following table.

| DATA BASE | CONTENT | DISK STORAGE REQUIREMENTS (MBYTES) |
|---|---|---|
| DB01 | - Geometric and load input data blocks | 4.7 |
| | - Stiffness and mass matrices data blocks | 87.2 |
| | - Load vectors data blocks | 7.7 |
| | - Residual strurture displacement vectors | 4.8 |
| DB02-1 | - OEF1X : element forces blocks | 21.0 |
| | - OPG1 : load vectors blocks | 10.2 |
| (1 month | - OQG1 : forces on single point constraints blocks | 9.3 |
| condit.) | - OUGV1 : displacement vectors blocks | 10.2 |
| | - SF1X : safety factors blocks | 2.3 |
| | - other blocks | 8.4 |
| DB02-2 | - OEF1X : element forces blocks | 23.1 |
| | - OPG1 : load vectors blocks | 12.1 |
| (3 year | - OQG1 : forces on single point constraints blocks | 11.2 |
| condit.) | - OUGV1 : displacement vectors blocks | 12.1 |
| | - SF1X : safety factors blocks | 3.2 |
| | - other blocks | 6.5 |
| DB02-3 | - OEF1X : element forces blocks | 19.2 |
| | - OPG1 : load vectors blocks | 9.9 |
| (50 year | - OQG1 : forces on single point constraints blocks | 9.1 |
| condit.) | - OUGV1 : displacement vectors blocks | 9.9 |
| | - SF1X : safety factors blocks | 1.7 |
| | - other blocks. | 7.4 |

## 5. OPERATING PROCEDURE

### 5.1 Introduction

In case of damage to structural elements, to assess the structural reliability of the damaged platform an appropriate set of loading conditions is applied to the structural model suitably modified to reflect the damage. The main points of the operating procedure are (see also tab. 2.2):

- automatic identification of the critical area and elements sensitive to the damage;
- automatic identification of the loading conditions that induce the maximum stresses in the elements of the critical area;
- automatic generation of a reduced structural model (i.e. damage model) in NASTRAN format including load vectors for the critical loading conditions and relevant boundary conditions for the reduced model;
- structural reanalysis and checks of the elements of the reduced model;
- visualization on graphic screen of the required parameters (displacements, forces, safety factors, etc.) for each desired portion of the structure
- analysis of the results and conclusions on the structural integrity of the platform.

The operating procedures to utilize the system and to evaluate the damage are described in a set of operating manuals.

### 5.2 Composition of the System

Besides the Data Bank and the software already described in Section 4 and MSC/NASTRAN program, the system is composed of "ad hoc" developed interactive software and DMAP routines for the selection and sorting of data included in the Data Bank.
The main programs are:

- DMAP Routine "SELECT" that allows:
  - the reading of blocks in the Data Bank
  - the selection of the desired subcases inside the blocks
  - the generation of the output files for all the designed blocks and subcases.
- Interactive program "SORTER", that allows:
  - the generation of a reduced file starting from the SELECT program output file (e.g. a set of elements inside a superelement etc.)
  - the sorting in ascending or descending order of the file according to a user defined key
  - the generation of an MSC/NASTRAN input file starting from one of the above described files.

## 5.3 Description of The Procedure

The flow diagram of the reanalysis procedure is reported in the following table:

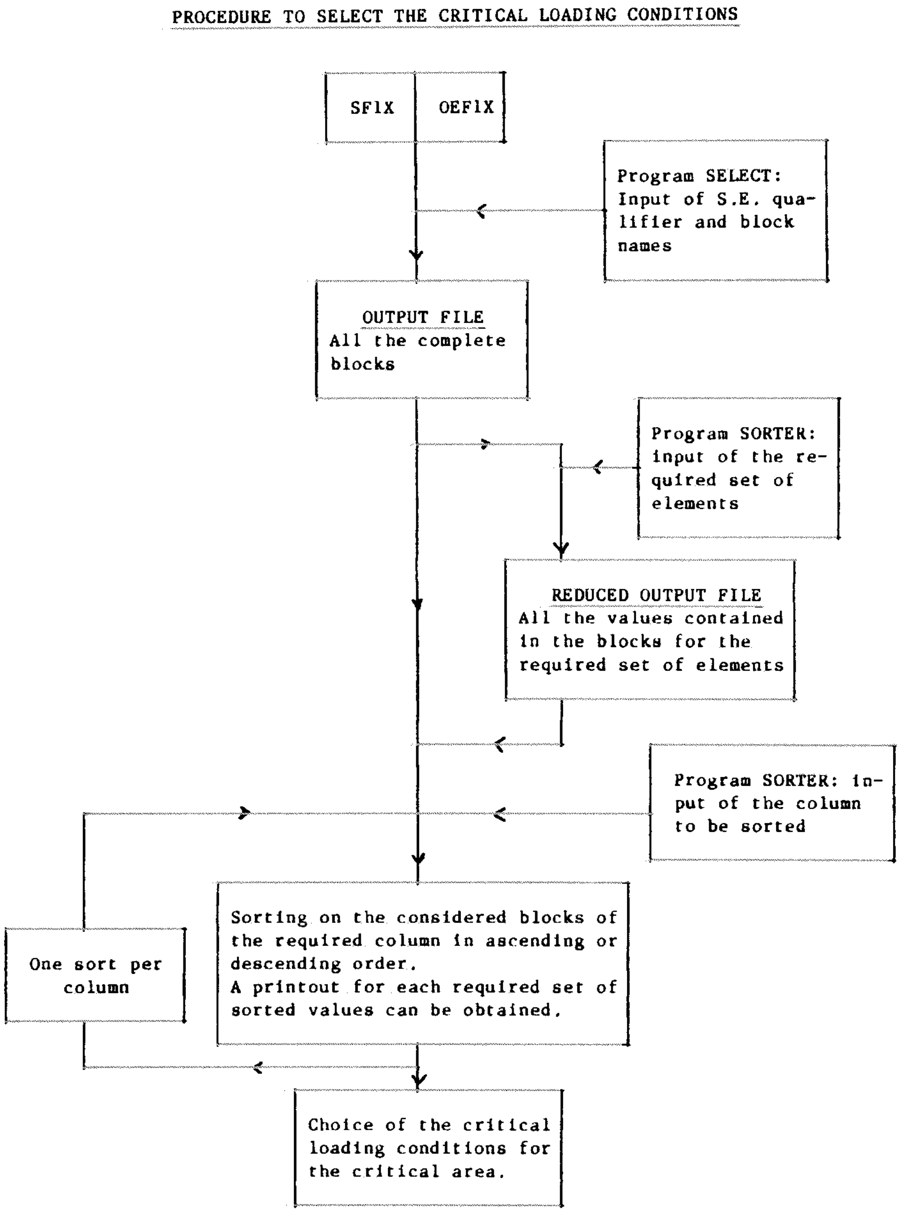
| OPERATION | SOFTWARE | INPUT | OUTPUT |
|---|---|---|---|
| IDENTIFICATION OF THE CRITICAL AREA | . SELECT<br>. SORTER (Elements and nodes) | . DATA BANK<br>. BOUNDARY NODES | . LIST OF ELEMENTS AND NODES OF THE CRITICAL AREA |
| IDENTIFICATION OF THE CRITICAL ELEMENTS | . SELECT<br>. SORTER (Forces and safety factors | . DATA BANK<br>. CRITICAL AREA | . LIST OF THE CRITICAL ELEMENTS |
| IDENTIFICATION OF THE CRITICAL LOADING CONDITIONS | . SELECT<br>. SORTER (Loads and displ.) | . DATA BANK<br>. LIST OF THE CRITICAL ELEMENTS | . LOAD VECTORS FOR THE CRITICAL LOADING CONDITIONS AND RELEVANT ENFORCED DISPLACEMENTS AT BOUNDARY NODES |
| UPDATING OF THE STRUCTURAL MODEL | / | . CRITICAL AREA | . NEW STRUCTURAL MODEL OF THE CRITICAL AREA |
| STRUCTURAL REANALYSIS | . NASTRAN<br>. COMB | . NEW REDUCED STRUCTURAL MODEL<br>. LOAD VECTORS FOR THE CRITICAL LOADING CONDITIONS AND RELEVANT ENFORCED DISPLACEMENTS IN BOUNDARY NODES | . NEW DISPLACEMENTS<br>. NEW FORCE DISTRIBUTION |
| STRUCTURAL CHECK | . NAISC 3<br>. NAISC 4<br>. PUNSHE<br>. DNV 77 | . NEW AND OLD FORCE DISTRIBUTION | . NEW AND OLD SAFETY FACTORS |

For the elements of the critical area, the SELECT program allows the sorting in ascending or descending order of the following blocks:

- SF1X (Safety factors - 8 columns)
- OEF1X (Element forces - 8 columns)
- OUGV1 (Nodal displacements - 6 columns)
- OPG1 (Load vectors - 6 columns).

The critical elements and the critical loading conditions are determined by the analysis of the data stored in these blocks.
The critical loading conditions are those which induce the lowest safety factors or the highest stresses in the Critical Elements that are the most stressed or the most sensitive to the modifications induced by the damage.
For the above reasons, the SF1X blocks are usually processed, although other parameters (element forces or displacements) can contribute to a better understanding of the structural behaviour.

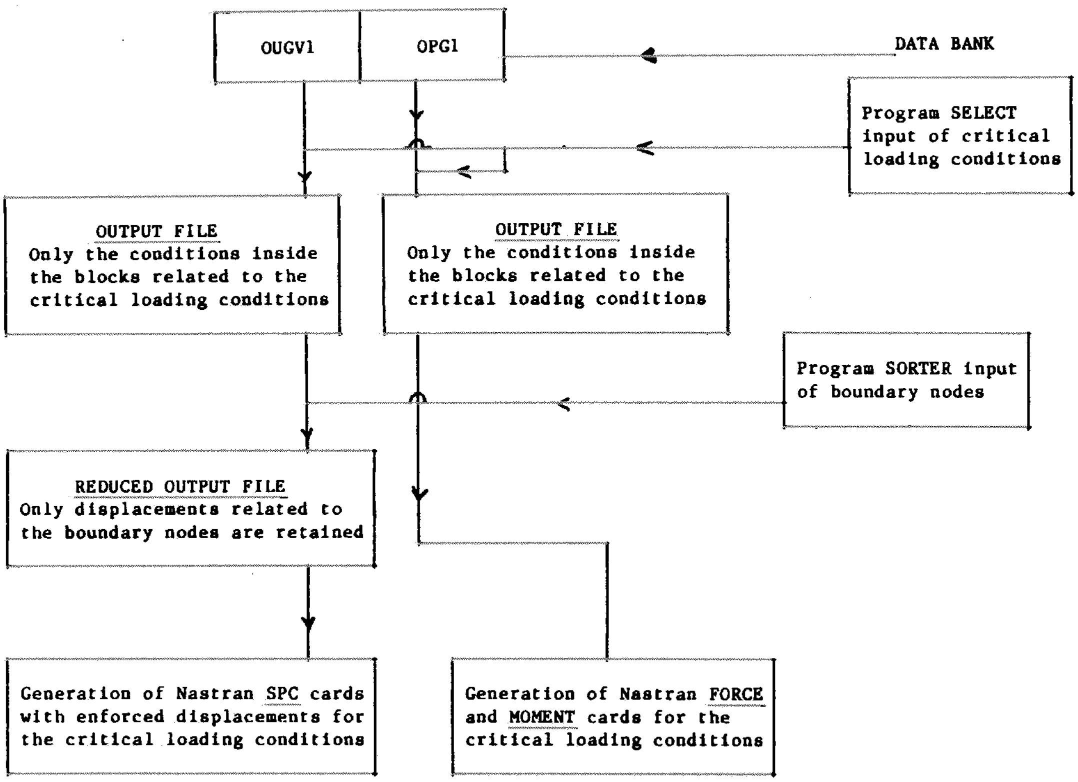
The following scheme illustrates the typical flow of this part of the procedure:




The procedure to generate:

- from blocks OPG1, the load vector (FORCE & MOMENT cards) to be applied to the nodes of the critical area for the critical loading conditions
- from block OUGV1, the enforced displacements of the boundary nodes of the critical area (SPC NASTRAN cards),

is reported hereafter.




To represent the damage on the updated structural model of the critical area, the damaged elements are not physically excluded from the model, but reduced stiffness characteristics in PBAR or PSHELL cards or end releases for bar elements are supplied to the members. In this way, the congruence of vectors, matrices and tables is maintained in the data bank.

The structural reanalysis is then performed on the Updated Structural Model, for the critical loading conditions applying the set of load vectors and corresponding enforced boundary displacements.

The comparison of the boundary reactions of the damaged model with respect to the ones of the intact structure shows the influence of the damage effects outside the boundaries of the reduced model and is a test of the correctness of the choice of the critical area. The force distribution, displacements and safety factors of the critical area are compared with the original values, and proper considerations contained in the operating manuals allow the evaluation of the safety level of the platform.

This part of the procedure does not fall within the scope of the present paper.

Following the considerations on the safety of the platform, the data bank is updated, if necessary, considering the damaged or repaired structure.

## 6. CONCLUSIONS

The Maureen platform Structural Reanalysis System (SRS) provides a rapid and low-cost computer analysis of structural integrity in the event of damage to primary steel works.
The first tests carried out on the procedure, in fact, demonstrated its capabilities: the assessment of the influence of a damage simulated on the framed structure of the platform was carried out in about four hours, a process which in the past has taken weeks or even months to be performed.
Besides being a new application of MSC/NASTRAN and DMAP processing, the system is a further step towards the enhancement of standards for emergency procedures in the offshore petroleum industry.