EDUCATION FOR OFFSHORE ENGINEERING

AND

APPLICATION TO A PLATFORM DESIGN

by

MOHD. RAMZAN MAINAL BSc

This thesis is submitted for the degree of Master of Science in the Department of Naval Architecture and Ocean Engineering, University of Glasgow.

United Kingdom

September 1986

DECLARATION

Apart from reference to the work of others this thesis is believed to be original.

ACKNOWLEDGEMENT

I wish to thank Professor D Faulkner, Head of Department of Naval Architecture and Ocean Engineering, University of Glasgow for his advice and material he made available to me.

My deepest gratitude to my supervisor, Dr. R M Cameron for his help and advise in planning, carrying out and reviewing this thesis. Without his continuous encouragement, support and suggestions, this work could not have been achieved.

I would also like to thank Dr. A Incecik for his help on the hydrodynamic analysis of the jacket platform.

I wish also to express my thanks and appreciation to all the staff in the Department who have contributed in one way or another to make this work possible.

I am grateful to my parents, brother, sisters and fiancee for their support and encouragement throughout this work.

Finally, I am greatly indebted to the Malaysian Government and Malaysian University of Technology who granted me the opportunity to do this work and has provided all the financial support during the course of study.

CONTENTS

SUMMARY

This thesis considers some of the patterns and requirements of education available in the United Kingdom for offshore engineering at the level of first degree and postgraduate courses. These requirements are illustrated by a design study for an offshore oil platform and associated steel jacket for waters east of West Malaysia in the South China Sea. Proposals are then made for courses in offshore engineering suitable for Malaysia.

The first part of the thesis traces the rise of the offshore industry which is mainly the offshore oil industry and the growth of tertiary education for this industry. It draws attention to the breadth of interests required and the absence of undergraduate courses which treat offshore engineering as a totally distinct branch of engineering under the accreditation procedure of a professional engineering institution. Demand is met by courses which represent sub-specialisation for students who begin in other branch of engineering. A similar pattern exist in the postgraduate education which if anything draws from a wider background.

Design of an offshore oil production platform illustrates the breadth of education required although the thesis limits numerical consideration to the design of steel lattice jacket under operational and environmental loadings. The relatively shallow water off the Malaysian coast is less severe compared to the North Sea.

The oil industry requires manpower at all levels of expertise

and the last part of the thesis considers a pattern for this education for technicians, professional and postgraduate engineers in Malaysia together with appropriate syllabuses.

NOTATION

A	cross -sectional area of cylinder
c	wave speed
c	circumference (Chapter 6)
C_D	drag coefficient
C_L	lift coefficient
C_M	inertia coefficient
C_m	coefficient (Chapter 6)
C_z	moment
d	brace outside diameter
d_i	inner diameter of cylinder
D	chord outside diameter
(D)	cumulative damage
E	Young's modulus of elasticity
F_T	force per unit length
F_x	horizontal force
F_y	vertical force
g	acceleration due to gravity
g	gap-parameter for gap between individual braces
H	wave height
H_s	significant wave height
I	moment of inertia
k	constant (Chapter 6)
k	wave number, $2\pi/L$
l	length of member

L	wave length
m	moment
m_0	moment of spectral density
n	number of waves above a selected wave height (Chapter 5)
n_i	number of cycles within stress interval
N	number of waves in a sea-state (Chapter 5)
N_i	number of stress cycles at which failure occurs
N_{KC}	Keulagan - Carpenter number
N_{Re}	Reynold's number
R	chord radius
R_b	brace radius
S	Strouhal number
S_s	Spectral density
t	brace wall thickness
T	chord wall thickness
T	wave period (Chapter 5)
T_{ms}	mean stress period
T_z	zero crossing period
U	water particle horizontal velocity
$\dot{U}$	water particle horizontal acceleration
α	amplification factor
α_1, α_2	coefficients (Chapter 6)
β	d/D
γ	R/T
ρ	density of water
σ_a	axial stress

σ_e	buckling stress
σ_p	residual stress
σ_s	stress deviation at 'hot spot'
σ_y	yield stress
σ_1, σ_2	maximum and minimum principal stress
τ	thickness parameter t/T (Chapter 6)
τ_p	punching shear stress
τ_{pa}	maximum punching shear stress
τ_{max}	maximum shear stress
η	instantaneous water level
ω	wave frequency

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION TO OFFSHORE INDUSTRY

1.1 DEVELOPMENT OF THE OFFSHORE INDUSTRY

A recent important part of marine technology is the discovery of mineral and fuel resources on and under the ocean floor, which has led to the rapid expansion of offshore operations concerning oil, gas and other related activities. The depletion of land-based mineral and energy resources and their ever increasing demand in modern society is one of the factors for the growing interest in the potential resources of the seas and oceans of the world.

Initially the search was concentrated on the more promising land areas, and occasionally extended into shallow water offshore where it was known that onshore reservoirs continued beyond the shoreline. In a relatively short period of time, the offshore industry moved towards more hostile and harsher environments. Increasingly deep water are exposed to severe weather conditions and sometimes low temperature. As a result, many new problems were posed and difficulties encountered; problems that had been rather insignificant in shallow and less rough waters suddenly were magnified in the recent fields. The great number of successful offshore platform installations indicate that at least reasonable solutions have been found to these problems.

Thus, over a period of forty years, the offshore industry has developed the capability of drilling for and producing oil and natural gas from the continental shelves of the world. Due to the ever increasing speed of the search and the spread of interest, many organisations now explore the waters of more than seventy countries.

Today, offshore oil represents about 25% of the world's oil production and the opportunities for the development and exploitation of what lies under the ocean seems to be almost limitless at the present time [15]. How to extract these minerals and energy resources economically and safely is the challenge that is confronting technology and industry today. The need for economical extraction is reinforced by recent price reduction. These are issues engaging the attention of policy makers, lawyers, scientists, industralists and governments of many countries. The answers are by no means certain, for the questions are often exceedingly complex, involving the interests and responsibilities of many agencies and countries.

The rapid development of the offshore oil industry has opened up exciting new fields in civil, structural and underwater engineering, geology and geophysics, soil and fluid mechanics, and in diving and many other underwater technologies. If ever there was a field of endeavour calling for multi-disciplinary and multi-national research and development programmes for exploration, inventiveness and ingenuity, this is it. One most urgent need, however, is to provide more education and training for the engineers in the new combined technology known as Offshore

Engineering.

1.2 OFFSHORE ACTIVITIES IN MALAYSIAN WATERS

The phenomenal growth during the past two decade in large engineering operations in ASEAN waters must also be seen as one part of the growing worldwide interest of offshore oil and gas activities.

Offshore drilling began in 1957 in East Malaysia and accelerated around 1966. About two thirds of the total footage in Sarawak and Sabah have been drilled during the past 20 years. Extensive exploration and drilling continues and has led to the discoveries of several large oil and gas fields in East and West Malaysia (Fig.1). In 1984, the estimated recoverable offshore reserves were listed at about 3000 million barrels of oil and 1.4 trillion m of natural gas [14].

The development of offshore exploitations in the ASEAN region has, inevitably, important implications for the educational institutions of higher learning which provide the training ground for engineers, at both professional and sub-professional levels, needed for the purpose. So far, there are no existing courses on offshore engineering or any related fields being held in Malaysia. It is therefore important to consider the possible role of the instituitions in producing the appropriate manpower to support the offshore engineering activities in Malaysian waters in particular and ASEAN waters in general.

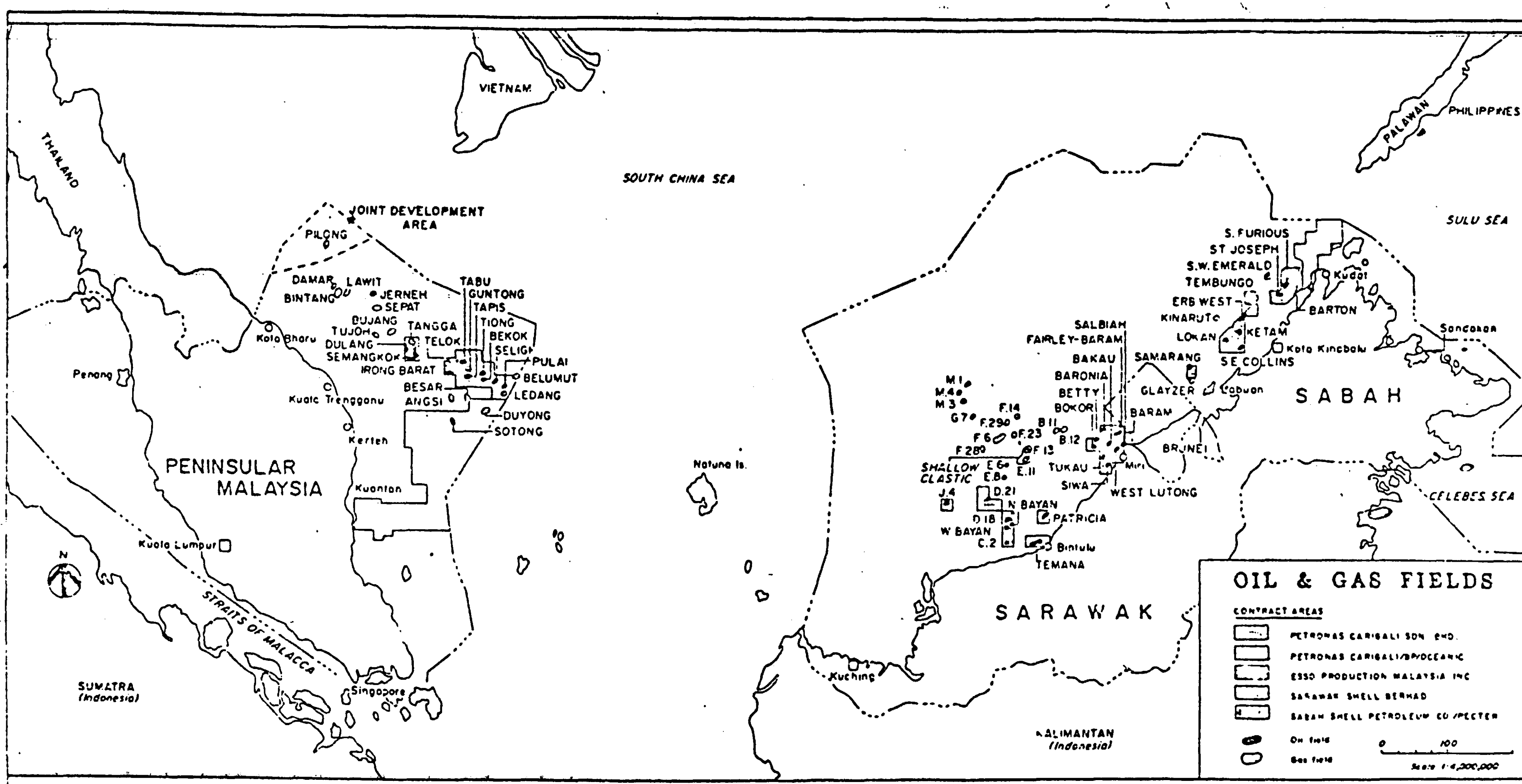


Fig.1 Oil and Gas Fields in Malaysia

1.3 DEFINITION OF OFFSHORE ENGINEERING

Broadly, offshore engineering comprises the development and application of technology for the advancement of ocean science and the exploration and utilisation of the oceans and their resources including the resources on and under the ocean floors. Offshore engineering, therefore, is not an engineering discipline of the type which, for example, electrical, mechanical, chemical and civil engineering represent. It is a typical systems engineering effort integrating many engineering disciplines and is directed at and controlled by the ocean environment as aeronautical and astronautical are directed at and controlled by the environment of air and outer space. In this respect, offshore engineering is very similar to naval architecture and marine engineering in the tradition sense which are also directed at and controlled by the ocean environment.

Offshore structures were originally largely based on civil engineering practice onshore. As launching, float out and positiong became more complex, the naval architect found a part to play in offshore structures. Extension of understanding of hydrodynamic forces and a broader interest in subsea vehicles and equipment heve reinforced the importance of general marine technology in offshore activities.

The exploitation of offshore oil and gas reserves also involves many activities and functions of the traditional petroleum and chemical engineers. However, whilst applying these traditional petroleum and chemical engineering principles, it is also necessary to take account of the constraints imposed by the offshore environment such as platform size, platform loading, wind and wave forces, salt water corrosion, the need to minimise noise and vibration, and the special hazards and safety factors involved.

In principle, this field encompasses activities such as marine petroleum and gas technology (drilling, production and distribution), and subsea mining. However, in the present development, emphasis has been given to those aspects of offshore engineering related to activities of design, fabrication and operation of offshore structures (vessels, vehicles, platforms, pipelines, etc.); to the design and use of equipment for power supply, computing, telecommunications and positioning, as well as for control of offshore operations such as diving, data acquisition and processing; and to the broad aspects of marine safety.

1.4 DEMAND FOR OFFSHORE ENGINEERS

It is obvious that need exists for practical engineers who understand the ocean's potentials and restraints and who can apply them realistically to basic engineering problems in, on and of the oceans. In short, the exploration, discovery and the development of offshore oil, gas and all that implies, has created a demand for new skills.

Oil companies need experienced personnel to train newcomers to the expanding field of offshore technology and this compounds a scarcity of skilled and experienced labour at all levels. When expansion has been particularly rapid it may be questionable if there has been sufficient training to ensure safety of personnel [50].

For the United Kingdom, North Sea developments in oil and gas have been the main catalyst for academic activities but exploration and exploitation of fields world wide has provided academic interest in many countries. In general, offshore engineering programs have been at graduate level and have attracted students from all the engineering disciplines and often from physics, geology and oceanography as well.

1.5 THE STRUCTURE OF THE OFFSHORE INDUSTRY

Before reviewing the existing education and training of offshore engineers, a closer look at the structure of the offshore industry and the type of personnel involved are essential. Who are they and do they all pose the same requirements of their newly engaged staff?. 'Offshore Industries' can be defined as those industries for which an important part of their bussiness lies in supplying goods or services geared to offshore activities, for example, exploration and production of oil and/or gas; exploration and production of minerals such as manganese nodules, sand and gravel; artificial islands for nuclear power or LNG terminals. Those industries can be divided into :

a. Major oil companies and mining companies.

b. Major project management and engineering design firms or groups.

c. Major fabricators for steel and concrete structures and installation firms.

d. Major service companies such as towing, diving and maintenance companies.

e. Education services.

f. Inspection approval and certification agencies at private, national and international level such as government department, classification societies, standards bureaus, and engineering institutions.

g. Numerous but smaller firms that supply all sorts of offshore services and goods to the above-mentioned major firms.

The following sections consider many aspects of the offshore industry starting with oil exploration and following the normal progression of events through to research and development activities.

1.5.1 Exploration

Exploration for oil and gas involves gaining some understanding of the geological structure of rocks under the sea floor, to determine the presence of oil reservoirs. Aerial magnetic surveys and seismic studies on land and sea provide data, analysed to detect geological structures which suggest the presence of oil. Interpretation of the resulting data allows operating groups to select areas which they consider to be the most promising, and over which they would wish to secure exclusive exploration and production rights and to assist in fixing a bid price for these rights. Survey contractors employ people from a wide range of disciplines but the work involves using sophisticated equipment to make sensitive measurement for which physicists, geophysicists and electronic engineers are often preferred. Seismic studies are carried out by teams of scientists and engineers often in remote and desolate places, so graduates with an interest in this kind of work have to be prepared to live in uncomfortable conditions.

The results of the survey work are subjected to sophisticated analysis and computer-aided modelling by the contractor and the oil company concerned. Exploration geologists from the oil company supervise the contractor's work, analyse the results and establish the geological structure of the sub-surface in their search for oil-bearing rock.

The decision to carry out exploration drilling is based on the weighted financial return taking the possible reserves distribution and geological risk into consideration. Offshore wells require expensive floating drilling rigs or drillships and are estimated to cost, generally in the range of £5 - 20 million [4].

1.5.2 Development Drilling

Some oil companies have drilling rigs of their own but the majority are hired from drilling contractors. All employ roustabouts, roughnecks, toolpushers and drilling engineers. Many of these employees have a background in mechanical engineering but this not always essential as training are usually provided. Drilling involves handling heavy tools and machinery. Wells many hundred metres deep are not necessarily drilled in straight lines and the drilling engineer is responsible for ensuring that the well enters the formation at the desired place. While the well is being drilled, the chips of rock which emerged in the drilling lubricant, known as mud, are analysed by geologists, to give further details of the geological structure. This activity, a part of well logging, is carried out by other contractors and the results analysed by the oil company's well site geologists.

More tests are done by wire-logging. Down hole instruments are used to measure the porosity, conductivity and many other physical parameters of the rock to find out if it is oil-bearing. Graduates with basic understanding of electronics are employed for this work, particularly electrical/electronic engineers and physicists, and they would produce 'logs' showing the changes in various measurements as the equipment is lowered down the well.

Reservoir engineers collect all the information which has been gathered about the prospective oilfield and using computers, produce maps and models of the field which are developed as more wells are drilled and extra information are available. Graduates in in petroleum engineering, chemical engineering, physics, and mechanical engineering are often employed as reservoir engineers.

1.5.3 Production

Before production begins, a production platform must be installed with all the facilities required to separate the mixture of sand, oil, gas and water which emerges from the wells. The high cost of providing the necessary facilities demand a large percentage of oil and gas to be extracted from the field and thus considerable effort is made to ensure maximum depletion of the reservoirs efficiently and economically. Some of the factors affecting the offshore oil and gas production decisions are given in Table (1) [4]. To illustrate the wide range of possibilities, typical facilities and cost for economic for offshore production of the reserves, catogaries are given in Table (2) for water depth down to 200 m. However, it should be noted that this is a simplified view since fields cannot be characterised by reserves alone.

Specialist engineering contractors are engaged to design and manufacture the production platforms and associate equipment. The common practice is that one contractor is appointed, for example, to design the platform structure, called the 'jacket' by the industry, while the contract for the design of the deck and the process facilities, known as 'topsides', is usually awarded to a second engineering firm. The construction, installation and commissioning

Table 1 : Factors Affecting Offshore Production Decisions [15]

Item		Strongly Influence
Water Depth, Area Extent, Productivity and Depth Below Seabed	-	Platform type, number of platforms and wells
Gas/Oil Ratio, Quantity and Quality	-	Facilities/topside specifications
Distance from Shore/Other Pipeline Systems	-	Export scheme

Table 2 : Typical Facilities and Costs for Economic Development of Certain Reserves [15]

Reserves (million barrels)	Facilities	Cost (million)
5 - 20	Production tanker	£100
20 - 50	Production tanker + mooring buoy + shuttle tanker	£200
50 - 100	Floating production facilities + offshore loading	£300
100+	Fixed steel/concrete platforms	£500 - 1500 each

work are handled by other specialist engineering firms. Figure (2) shows the technologies involved in designing an offshore platform. Generally graduates from civil engineering, ocean engineering, naval architecture, mechanical engineering, physics, geology, chemical engineering and architecture are employed to design the platforms.

1.5.3.1 Initial Project Development of An Offshore Platform

As indicated in Fig.(3), the initial project development of an offshore platform goes through four main phases; feasibility, platform definition, preliminary engineering often known as front-end engineering, and execution. Among the important stages include:

1.5.3.1.1 Initial Studies and Investigations

Initial studies and investigations typically include soil surveys, sea state and weather studies, pipeline route surveys or other delivery systems and, in some cases preliminary model testing.

1.5.3.1.2 Conceptual Design

Conceptual design involves arriving at a basic technical solution utilizing input from the initial studies and investigations, along with already established general specifications and prior experience. This work includes specifying the process to be used for handling the oil and/or gas, the number, size and type of platforms, the layout of the units on the deck and the type of offshore loading system or pipeline configuration.

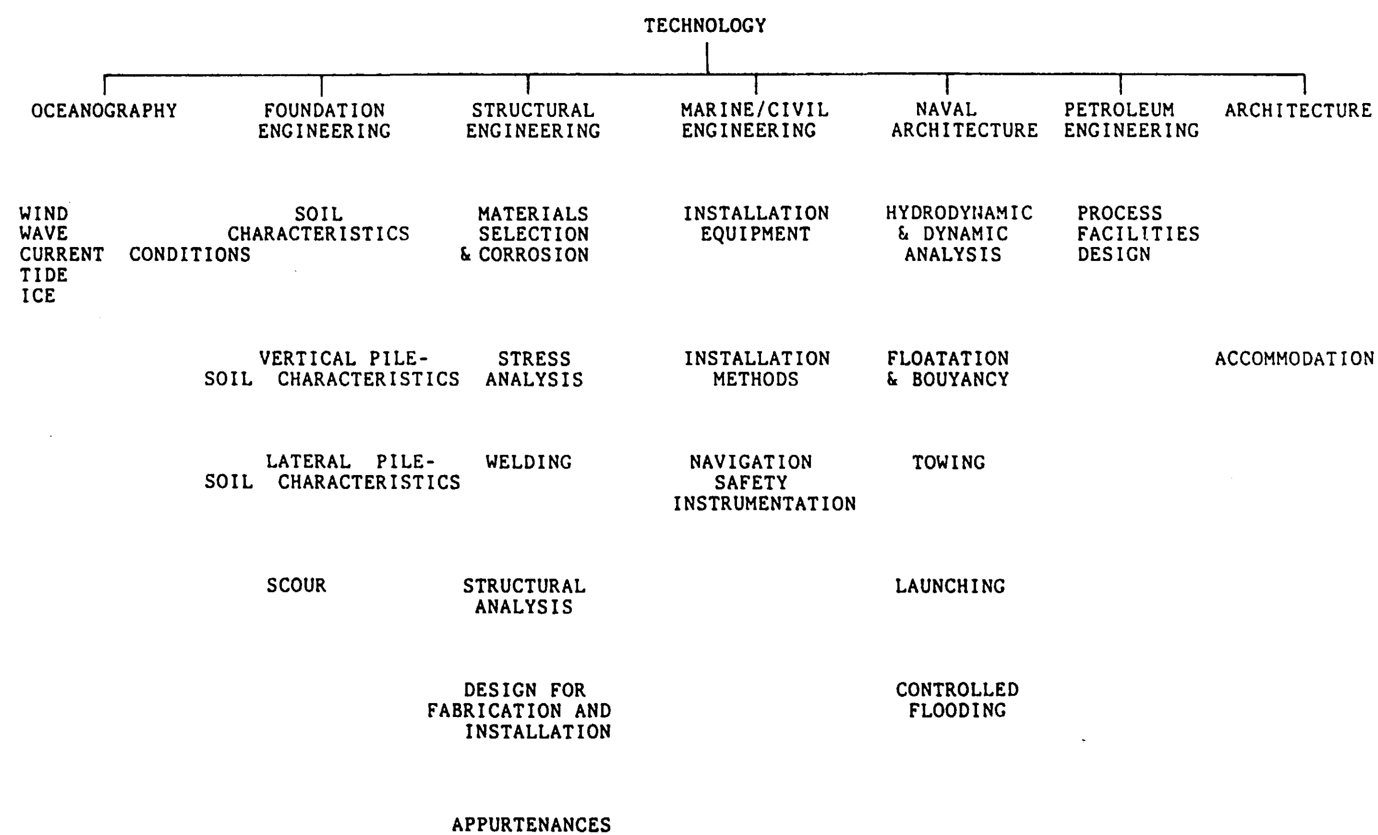


Fig.2 Technologies Involved In Offshore Platform Design (based on [9])

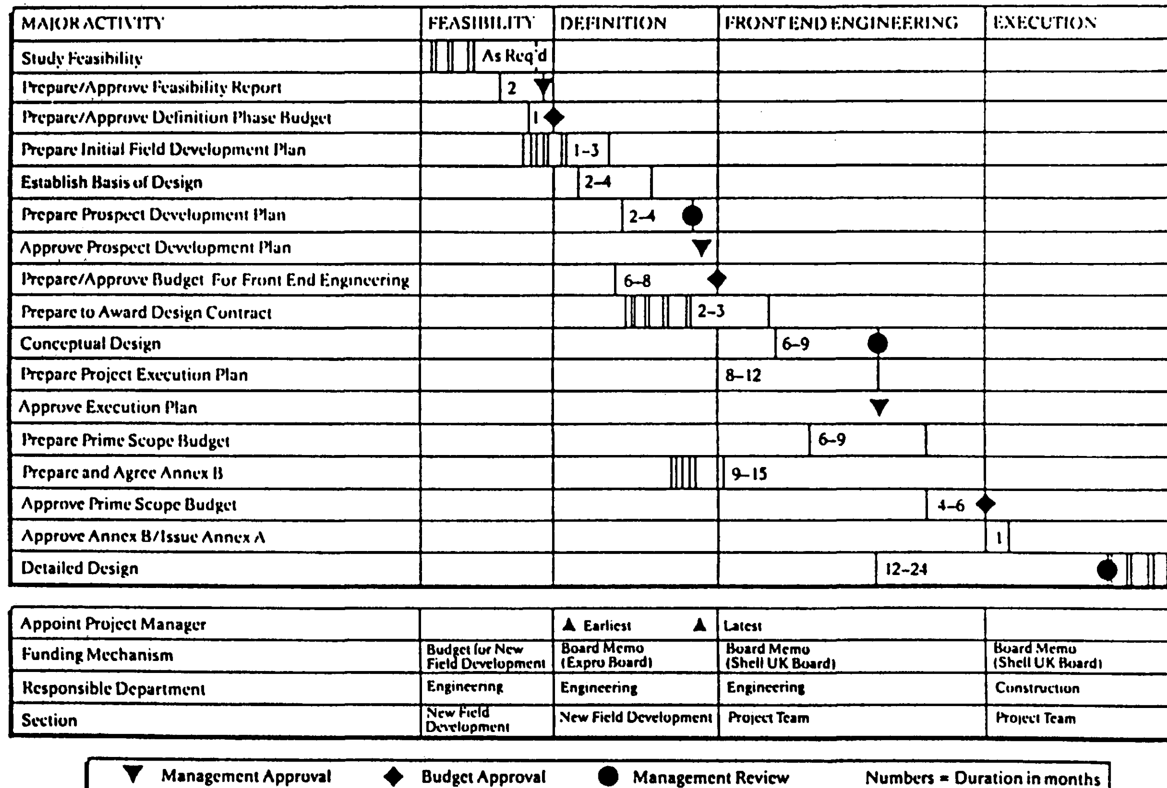


Fig.3 Typical Initial Project Development Phase [49]

1.5.3.1.3 Detailed Design

Detailed design is the work involved in transforming the basic outlines into coordinated systems, along with detailed drawings and specifications which will then be used by fabricators and suppliers to produce and assemble or install all the components. Fig.(4) shows a typical network for a major offshore construction project.

A project management team is usually formed by the oil companies with the intention to allow a smooth and efficient interface with the various contractors and suppliers used to carry out the work. A typical team can comprises some 30 to 40 personnel from the operator's side and a further 200 or so are contract personnel hired from agencies as required. Fig.(5) shows a typical project management team.

1.5.4 Research and Development

An offshore related company carries out reseach and development activities in order to improve the existing manufacturing processes, novel methods of extracting oil from a well and the development of new geophysical techniques, topside weight control of platforms and to improve existing products.

At the time research may seem to be a costly business, but it should be seen as an investment in the future of a company. A few of the research topics currently being studied are:-

a. the acquisition of wind, wave and current data, as the

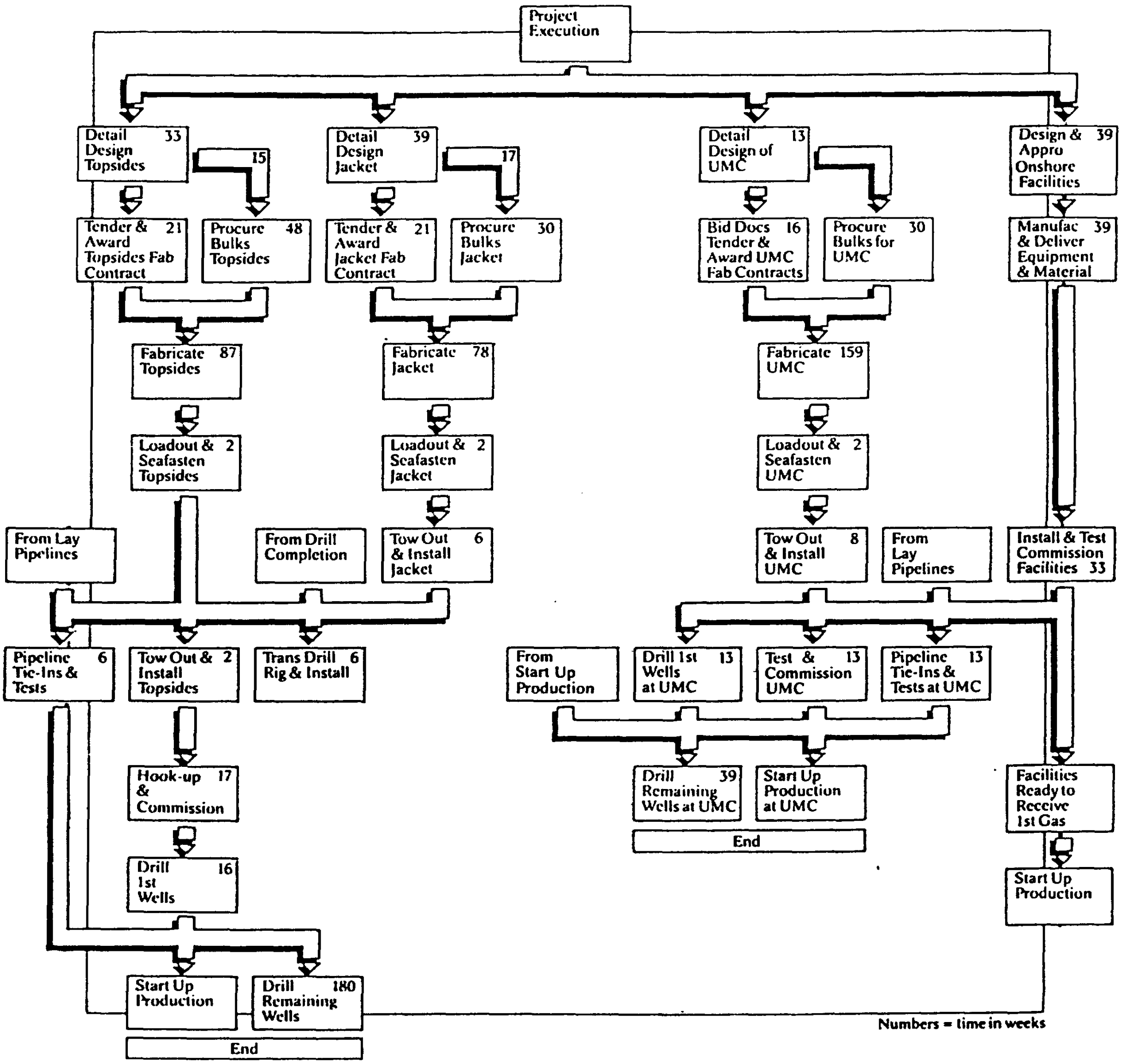


Fig.4 Typical Network For Offshore Platform Project [49]

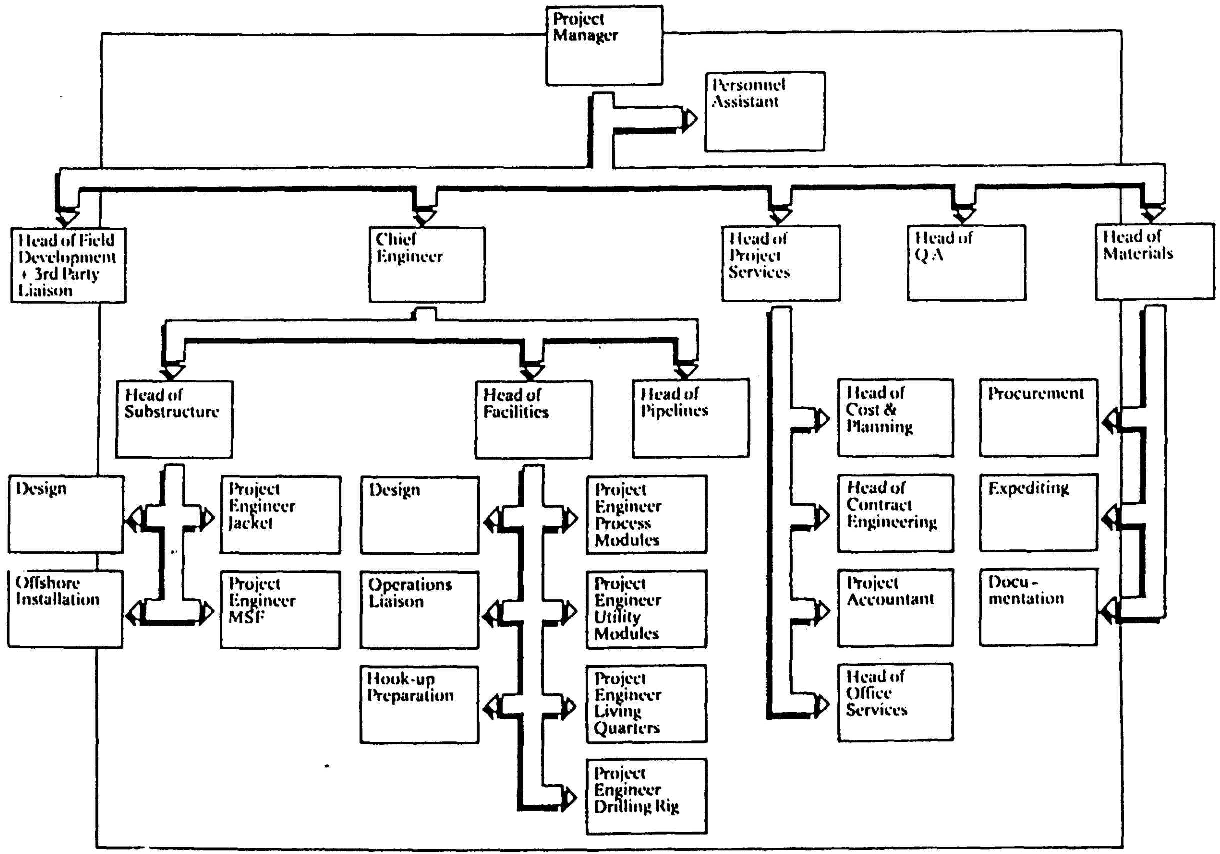


Fig.5 Typical Project Management Team [49]

effects of enviromental factors are basic to the design of offshore installations for hostile environment;

b. the prediction and measurement of the effects of forces imposed by waves and currents on offshore installations;

c. studies of seabed stability, of importance for both 'jack-up' drilling rigs and for large concrete gravity platforms;

d. studies of the problems associated with corrosion, fatigue, of the materials used in both steel and concrete platforms;

e. monitoring of the performance of steel jacket and concrete gravity structures already operational such as in the North Sea;

f. the safety of electrical equipment used underwater by divers; and

g. the effect of impacts from fishing boats' trawl boards and dropped anchors on the integrity of underwater pipelines.

Much of the above research work has produced useful results but new problems are being encountered which will become the subject of new research projects. High priority is currently being given to research aimed at easing the work load on divers; this involves work on the development of manned and unmanned submersibles for inspection of pipelines; on improved non-destructive testing and on vibration monitoring and acoustic emission techniques. Other current fields of research include:

a. tethered buoyant platforms;

b. single point mooring system;

c. positioning, mooring and anchoring systems;

d. sub-sea completions and sea-bed production;

e. systems for marginal fields;

f. underwater tools and power sources;

g. deepwater drilling capability;

h. drilling in ice covered waters; and

i. maintenance of offshore structures.

In order to undertake a spread of research activities as mentioned above, a wide range of skills is required. A typical research centre could employ 300 people or more. At least a half of the employees would be graduates such as naval architects, physicists, geophysicts and all the engineering disciplines. A further 15% or so of the employees would be technical or engineering assistants who would posses technical qualifications, and in addition there would be a back-up of craftsmen, draughtsmen and process operators to run small scale process plants, librarians and technical information staff.

Table (3) shows the estimated staff complements during the exploration, development and production stages of offshore hydrocarbon extraction which have been prepared by a Petroleum Industry Training Board group in cooperation with the Education Committee of the Institute of Petroleum between 1973 - 1980 [51]. Leave entitlement will increase the total number required.

Table (4) shows the employment of professional grades related to offshore operations in the United Kingdom between 1973 - 1980.

Table 3 : Estimate Staff Complements During Offshore Exploration, Development and Production [51].

	EXPLORATION		DEVELOPMENT		PRODUCTION	
SHORE	OFF	ON	OFF	ON	OFF	ON
CATEGORY						
Drilling Supt.	2	1	2	½	-	-
Toolpusher	3	-	3	-	-	-
Drilling Eng.	2	1	½	½	-	-
Petroleum Eng.	1	1	1	1½	-	1
Production Eng.	-	-	2	½	2	2
Geologist	2	1	2	-	-	-
Geophysicist	-	1	-	-	-	-
Mechanical Eng.	2	1	2	1	2	1
Electrical Eng.	2	1	3	3	3	3
Instrument Eng.	-	-	½	1	½	1
Mariner	3	1	-	½	-	½

Notes:

1. The figure assume that the operator employs all personnel. The fact that contractors are commonly used for some operations may increase the figures slightly, particularly those employed onshore.
2. The figure for drilling superintendents includes those in charge of floating rigs (barges).

Table 4 : Employment of Professional Grades 1973 - 1980 [51].

CATEGORY	1973	1976	1980	APPROX. ANNUAL INCREASE
Drilling Technologists	230	350	450	30
Petroleum Engineers	110	230	370	35
Geologists	80	120	150	10
Geophysicists	20	30	40	5
Mechanical Engineers	120	210	340	30
Electrical Engineers	160	310	500	50
Instrument Engineers	20	50	80	10
Mariners	100 - 120	130 - 170	180 - 260	10 - 20
Total	860	1470	2190	190

Note:

1. Drilling Technologists include Superintendents, Toolpushers and Drilling Engineers.
2. Petroleum Engineers include Production and Reservoir Engineers and other jobs that come within these functional classifications.
3. Electronic Engineers are included in Electrical Engineers.
4. The higher figure under Mariners denotes an Oilfield Installation Manager on each manned fixed platform.

CHAPTER 2

SURVEY OF BRITISH OFFSHORE ENGINEERING EDUCATION

2.1 INTRODUCTION

In recent years there has been a rapid expansion in the offshore oil and gas producing industries centred around the developments in the North Sea. Since 1980, offshore investment in UK waters has risen from 20% to 28% of the total industrial investment in the UK; no other single industrial sector compares in these investment term. About £22 billion has already been invested in the UK offshore business and £60 billion will be spent developing around 80 new (though generally small) fields [60].

All would agree that the industries engaged in offshore activities do have a need for engineers and technicians which would posses knowledge of the offshore environment including all engineering associated with exploitation and production of ocean and seabed resources. How have the higher institutions in UK reacted to this need? There have been several steps taken by certain universities and colleges, but compared with the development in the North Sea itself, these institutions have reacted rather slowly. For this there are three reasons:

1. It must always be difficult for a University to anticipate the needs of the Industry in (say) five to ten years from now, especially if the development occurs over a short time and the technical requirements for the development are ill-defined.

2. Many universities may find it difficult to break through the rather independent attitude of the various faculties or departments, which however is absolutely essential if an offshore course or department is to be established.

3. The absence or scarcity of staff with background, actual experience or even interest in the new field. If developments are rapid industrial renumeration will be high and few will be attracted back into tertiary education to redress this situation. The present relative recession may be useful in this respect.

Nevertheless, there is growing evidence that the UK is seen as an international education and training centre by the offshore oil and gas related industries. Compared with the higher institutions abroad, institutions in the UK are rising to the challenge and are rapidly enlarging their knowledge and improving the skills and techniques to meet the demand of offshore related engineers.

Apart from action by universities, colleges and individual companies, any coordinated action that has taken place in UK has followed from a series of major reports initiated by government bodies and these are listed in Table (5). The author has no intention of commenting individually on the recommendations of these various reports, many of which have now been implemented. Following the recommendations of these reports, significant sums of government and industry money have been spent to improve offshore engineering education and training.

Table 5 : Reports dealing with training and education for offshore occupations.

1972 -	Study of potential benefits to British Industry from offshore oil and gas developments for Department of Trade and Industry by IMEG.
1973 -	Education and training for offshore development. For Department of Employment by Inter-Department Working Party.
1973 -	Report on Marine Technology for Science Research Council by Aeronautical and Mechanical Engineering Committee.
1974 -	The discovery of offshore oil and gas; manpower implications for Manpower Services Commission by Begg and Fyfe.
1974 -	Deep Diving Training in the UK for Training Services Agency by Underwater Training Task Group.
1974 -	Offshore engineering by Select Committee on Science and Technology.
1976 -	Marine Technology for Science Research Council by Task Force of the Engineering Board.
1976 -	Symposium on Education and Training for Naval Archtecture and Ocean Engineering by the Royal Institution of Naval Architects.
1976 -	Report on offshore operations by Petroleum Industry Training Board by Task Force.
1979 -	UNESCO Report on Marine Science (No.4):- syllabus for training technicians.
1981 -	PREST: A Survey in Marine Education in UK.
1982 -	UNESCO Report on Marine Science (No.25):- Ocean engineering teaching at the University level.
1984 -	UNESCO Report on Marine Science (No.26):- Global survey and analysis of post-graduate curricula in ocean engineering.

Opportunities for formal offshore engineering education in UK are limited compared to other engineering disciplines, although there is a variety of courses available reflecting different levels of academic attainment in this field. Most of the institutions have preferred to conduct offshore engineering options in traditional undergraduate curriculum; postgraduate or other related advanced courses leading to a higher degree or diploma; or to conduct short courses in detailed aspects of offshore technology.

A brief summary of offshore engineering education in Europe and elsewhere was given in 1984 by UNESCO, but there have been several developments in the last two years as industrial interest in offshore activity has become more intense.

2.2 THE SURVEY

The objectives of this survey include:

1. To survey which institutions have offshore engineering curricula,

2. To obtain information on the nature of these curricula,

3. To determine the similarity of curricula by noting the frequency of occurence of specific courses and subjects,

4. To provide guidance in the design of curricula in the field of offshore engineering.

Initially it was decided to concentrate on taught courses at the undergraduate level having offshore engineering subjects, whether compulsory or optional, but it was felt that the postgraduate courses also have to be considered since these would offer useful comparison between the undergraduate and the postgraduate syllabus.

Review of all undergraduate and postgraduate courses and previously related reports were then made. Several courses were chosen if they appeared to contain sufficient offshore related tuition for this purpose. A questionnaire was then sent to several heads of department for each relevant course in November 1985. The questionnaire asked for details of the subjects covered in the course as well as the nature of the courses. Visits were made to the following institutions:

1. Robert Gordon Institute of Technology
2. University of Newcastle upon Tyne
3. Cranfield Institute of Technology
4. University of Heriot-Watt
5. University College London
6. Sunderland Polytechnic

The visits produced a great deal of information and it is believed that this survey have identified the main courses in this area. The survey summaries the findings based on previous reports and universities calenders, and information from talks with several heads of departments of the relevant courses, and thus this survey presents much information not readily available elsewhere.

2.3 UNDERGRADUATE COURSES

There have been discussions in many forums whether Offshore Engineering should only be considered a discipline for postgraduate education or whether it should be treated like many smaller branches of engineering such as Aeronautical Engineering as a discipline for undergraduate and postgraduate specialisation.

A list of institutions offering undergraduate courses with Offshore Engineering contents is given in Table (6) but only several of these will be discussed in detail.

2.3.1 Heriot-Watt University

Within the UK university system, Heriot-Watt has become one of the leading centres for marine technology education and research and a major portion of this is generated within the Department of Offshore Engineering which was set up in 1974. So far, this is the only university to offer the B.Eng degree in Offshore Engineering. Heriot-Watt has take on the advantage of its (Scottish) four-year degree structure in making this departure from the traditional engineering disciplines.

Table 6 : Universities and Polytechnics Offering Undergraduate Courses in Offshore and Related Technology

University	Course
Glasgow	B.Sc in Naval Architecture and Ocean Engineering
Heriot Watt	B.Eng in various Engineering disciplines with offshore option in the third and fourth year
Leeds	B.Sc in Mechanical Engineering (final year option in Ocean Engineering)
Liverpool Poly	B.Sc in Maritime Studies
Liverpool	B.Sc in Oceanography and B.Eng with Civil and Maritime Engineering (4 year extended course)
Newcastle	B.Sc in Naval Architecture and Shipbuilding, and B.Sc in Marine Engineering
North East London	B.Sc in Mechanical Engineering (final year option and project of Underwater Technology)
Plymouth Poly	B.Sc in Mechanical Engineering (final year option in Offshore Engineering) and B.Tec in Civil Engineering (option in Marine Civil Engineering)
Strathclyde	B.Sc in Naval Architecture and Ocean Engineering
Sunderland Poly	B.Sc in Nautical Studies
UCL	B.Sc in Naval Architecture and Ocean Engineering
North Wales, Bangor	B.Sc in Oceanography with Soil Science
Swansea	B.Sc in Oceanography
East Anglia	B.Sc in Environmental Scinces (optional courses include Oceanography, Geophysics, Marine and Coastal Management)
UMIST	B.Sc in Chemical Engineering and B.Sc in Civil Engineering (both with final year option in Offshore Engineering)
UWIST	B.Sc in Maritime Studies and B.Sc in Maritime Geography

Offshore Engineering undergraduates begin with a 'parent' discipline from one of the following: Chemical and Process Engineering, Civil Engineering, Electrical and Electronic Engineering, and Mechanical Engineering. The first two years of the course are spent pursuing the parent subject. In the third year, study of Offshore Engineering subjects is expanded whilst a significant amount of time is still spent on studies in the parent department. In the final year, there is a decreased involvement with the parent discipline and about two thirds of the time is spent studying Offshore Engineering subjects. Fig.(6) shows how the material is allocated while Table (7) gives the detailed breakdown of the course. The detailed syllabus of the subjects undertaken are given in Appendix A.

The course began in 1974 with an intake of eight students in the third year of the course. Fig.(7) shows the number of students graduating from the course from 1980 to 1985.

2.3.2 University of Glasgow

Universities with existing Departments of Naval Architecture have all to a greater or lesser degree incorporated subjects of special relevance to offshore engineering in their courses. This has been done by greater emphasis on Ocean Dynamics, by the introduction of Ocean Engineering and by consideration of the special types of craft and structures which are part of the offshore industry.

In the case of the University of Glasgow the title of the

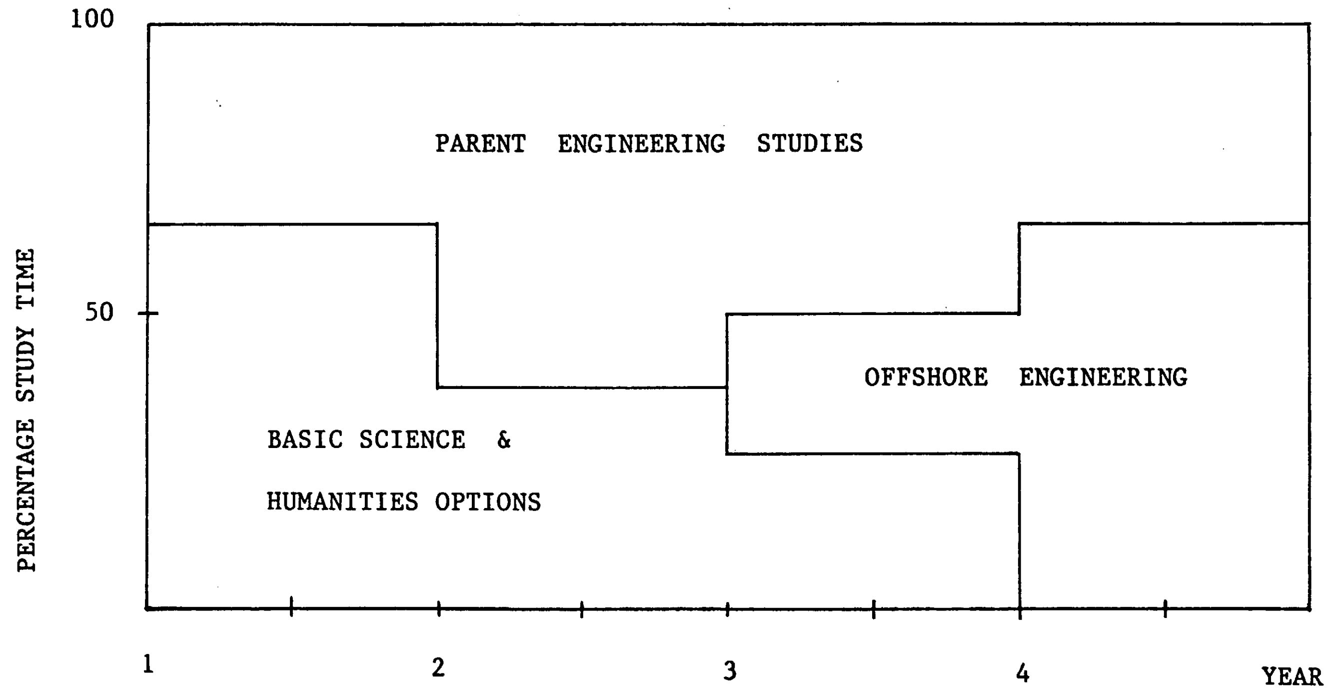


Fig.6 Material Allocation for B.Eng in Offshore Engineering, Heriot Watt University

Table 7 : Course Structure of BEng in Offshore Engineering (Heriot-Watt)

Class	Average Nos. of hours per week: Lect.	Lab/DO/Tut.	Total	Examination Papers
FIRST AND SECOND YEAR				
As for students of Civil, Chemical and Process, Electrical and Electronic or Mechanical Engineering				
THIRD YEAR (a)				
Offshore Engineering (Chemical)				
27.301 Environment and Design	2	2½	4½	1D
27.302 Measurements and Control	2	2½	4½	1D
25.301 Chemical Engineering IIIA	2	2	4	1D
25.302 Chemical Engineering IIIB	2	2	4	1D
25.304 Chemical Engineering IIID	2	2	4	1D
11.304 Mathematics III	2	1	3	1E
	12	12	24	6
Offshore Engineering (Civil)				
27.301 Environment and Design	2	2½	4½	1D
27.302 Measurement and Control	2	2½	4½	1D
21.398 Applied Hydraulics and Engineering Design)	2			C
21.392 Geotechnics)	2	4½	10½	1D
21.393 Structural Mechanics)	2			1D
11.301 Mathematics III	2	1	3	1E
	12	10½	22½	6
Offshore Engineering (Electrical)				
27.301 Environment and Design	2	2½	4½	1D
27.302 Measurements and Control	2	2½	4½	1D
22.301 Electrical Engineering	2	1	3	1D
22.302 Electrical Engineering	2	1	3	1D
22.303 Electrical Engineering III	2	1	3	1D
11.302 Mathematics III	3	1	4	1E
	13	9	22	6
Offshore Engineering (Mechanical)				
27.301 Environment and Design	2	2½	4½	1D
27.302 Measurement and Control	2	2½	4½	1D
23.301 Machine Dynamics	1½	1	2½	1D
23.3A8 Control Engineering	2/-/-(l)	1/-/-(l)	3/-/-(l)	C
23.303 Strength of Materials	1½	1	2½	1D
23.3A6 Mechanical Engineering Design	1	2	3	C
11.303 Mathematics II	2	1	3	
	12/10/10	11/10/10	23/20/20	5

Class	Average Nos. of hours per week: Lect.	Lab/DO/Tut.	Total	Examination Papers
FOURTH YEAR				
Offshore Engineering (Chemical)				
27.401 Offshore Engineering IVA	2	4	6	1E
27.402 Offshore Engineering IVB	2	4	6	1E
27.403 Offshore Engineering IVC	2	—	2	1E
25.402 Chemical Engineering IVB	2	2	4	1E
25.401 Chemical Engineering IVA) or) 25.404 Chemical Engineering IVD)	2	2	4	1E
27.409 Group Project (b)	—	2	2	C
27.410 Course Work (c)	—	—	—	C
	10	14	24	5
Offshore Engineering (Civil)				
27.401 Offshore Engineering IVA	2	4	6	1E
27.402 Offshore Engineering IVB	2	4	6	1E
27.403 Offshore Engineering IVC	2	—	2	1E
21.471 Geotechnics	2	1	3	1E
21.472 Structural Engineering	2	1	3	1E
27.409 Group Project (b)	—	2	2	C
27.410 Course Work (c)	—	—	—	C
	10	12	22	5
Offshore Engineering (Electrical)				
27.401 Offshore Engineering IVA	2	4	6	1E
27.402 Offshore Engineering IVB	2	4	6	1E
27.403 Offshore Engineering IVC	2	—	2	1E
22.402 Electrical Engineering IVB	2	1	3	1E
22.410 Electrical Communications	2	1	3	1E
27.409 Group Project (b)	—	2	2	C
27.410 Course Work (c)	—	—	—	C
	10	12	22	5
Offshore Engineering (Mechanical)				
27.401 Offshore Engineering IVA	2	4	6	1E
27.402 Offshore Engineering IVB	2	4	6	1E
27.403 Offshore Engineering IVC	2	—	2	1E
23.451 Machine Dynamics	3	—	3	1E
23.403 Strength of Materials	3	—	3	1E
27.409 Group Project (b)	—	2	2	C
27.410 Course Work (c)	—	—	—	C
	12	10	22	5

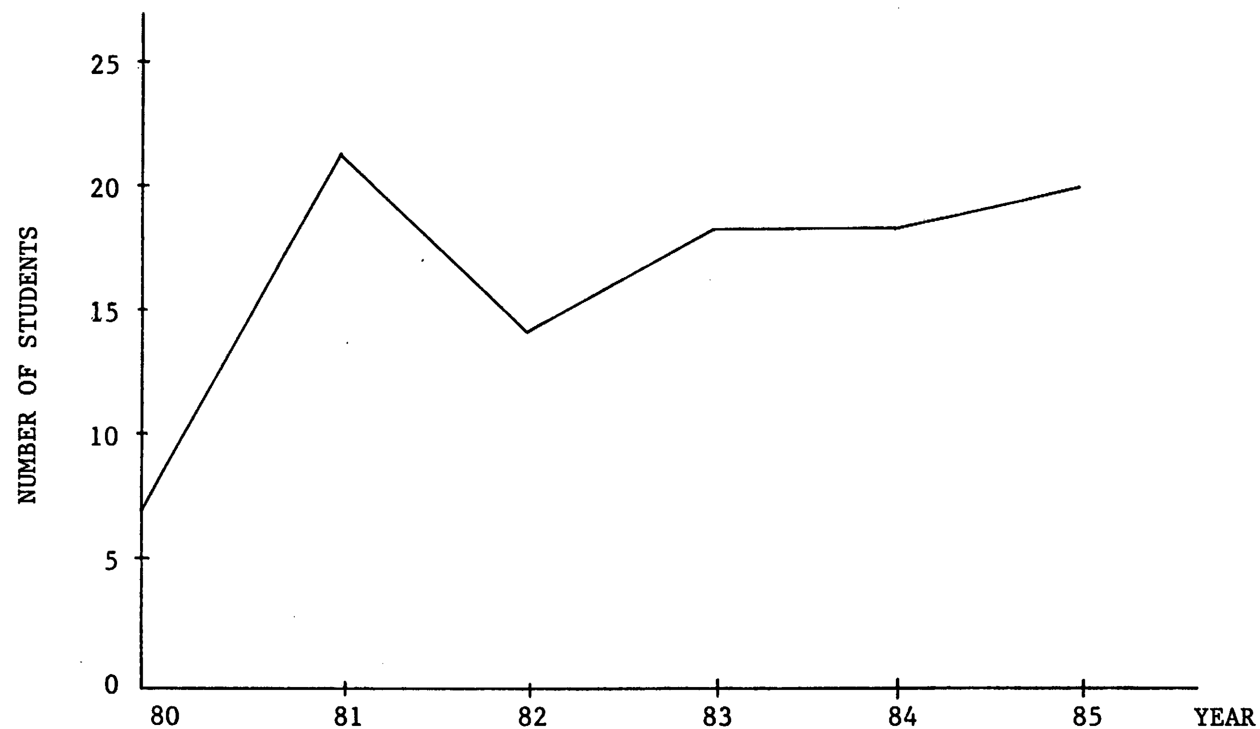


Fig.7 Number of Students Graduating from Heriot Watt University

Department was altered to be that of Naval Architecture and Ocean Engineering in 1974. At that time it was intended that three sub-specialisations would be on offer in the final year of the course, namely Naval Architecture, Transocean Transportation and Ocean Engineering and that this would be done by a range of choice of largely final year subjects. Experience showed that most students chose the same options perhaps because they responded to prevailing job opportunities in the same way.

At present the tendency is to reduce options partly in conformity to Engineering Council accreditation considerations but Table (8) indicates the current sub-specialisations. It is important to understand that the basic compulsory subjects of mathematics, engineering sciences and naval architecture are not given in the table. The recommended courses must be taken for a particular sub-specialisation.

2.3.3 Sunderland Polytechnic

In 1971, the Department of Naval Architecture at Sunderland Polytechnic and the Department of Navigation (now Nautical Science) at South Sheids Marine and Technical College (now South Tyneside College) jointly were successful in having their submission to conduct a course BSc in Nautical Science accepted by C.N.A.A. Accordingly, in 1976, it was considered by the Course Board of Studies, that the broadly-based course was particularly suitable for amendment so as to allow it to satisfy the growing need for

Table 8 : Sub-Specialisation within Naval Architecture and Ocean Eng. at University of Glasgow

SUBJECT GROUP	YEAR	1st, 2nd, 3rd YEAR RECOMMENDED COURSES	RECOMMENDED 4th YEAR COURSES
Naval Architecture	3 3 3	Mathematics EIII (2) Ship Production III (1) Transocean Trans- portation II (1) Marine Systems III (1)	Naval Architecture Design IV (2) Ship Hydrodynamics IV (2) Ship & Ocean Structures IV (2) Plus two units from: Ship & Ocean Dynamics IV (2) Ocean Engineering IV (2) Oceanography IV (2) Fluid Mechanics IV (2) Materials & Structures IV (2)
Naval Architecture (with Engineering Management specialization)	1 2 3 3 or 4 3 or 4 3 or 4 .2 , 3 or 4	Economics EI (2) Engineering Management I (2) Mathematics EIII Engineering Management III (2) Accountancy EIII (2) Ship Production III (1) Transocean Trans- portation II (1)	8 units from NAOE Honours plus Eng. Management IVB or Economics III
Ocean Engineering*	1 3 3 or 4	Geology EI (2) Mathematics EIII (2) Soil Mechanics III (2)	Ocean Engineering IV (2) Ship & Ocean Dynamics IV (2) Ship & Ocean Structures IV (2) Plus 2 units from: Ship Hydrodynamics IV (2) Naval Architecture Design IV (2) Oceanography IV (2) Materials & Structures IV (2)

* It is not possible to combine the Ocean Engineering option with Engineering Management.

technologists and technical management in the construction, operation and serving of oil rigs and associated installations and in the various technical aspects of seabed exploration.

The currently approved (1979) course structure is shown in Fig.(8). Examination of this figure shows that the final year of the course consists of a common core of three subjects plus one or two Suites of two subjects each; Suite 'A' (marine transport technology) and Suite 'B' (offshore technology). The particular Suite taken by any student is decided in the second year of the course which consists of a common set of six subjects, plus either Navigation or Marine Structure depending on whether Suite 'A' or 'B' is to be taken. The details of the arrangement of the course, giving an overview of the subjects and their place in the course structure and the details of appropriate offshore engineering subjects is given in APPENDIX A.

2.4 Postgraduate Courses

Offshore Engineering education as a postgraduate taught course in the United Kingdom started in the following institutions;

1. Liverpool and Manchester Universities in 1970, and
2. University College London in 1972.

Since then, several institutions have managed to conduct offshore related courses at advanced level. These courses not only attracted practising engineers from different engineering

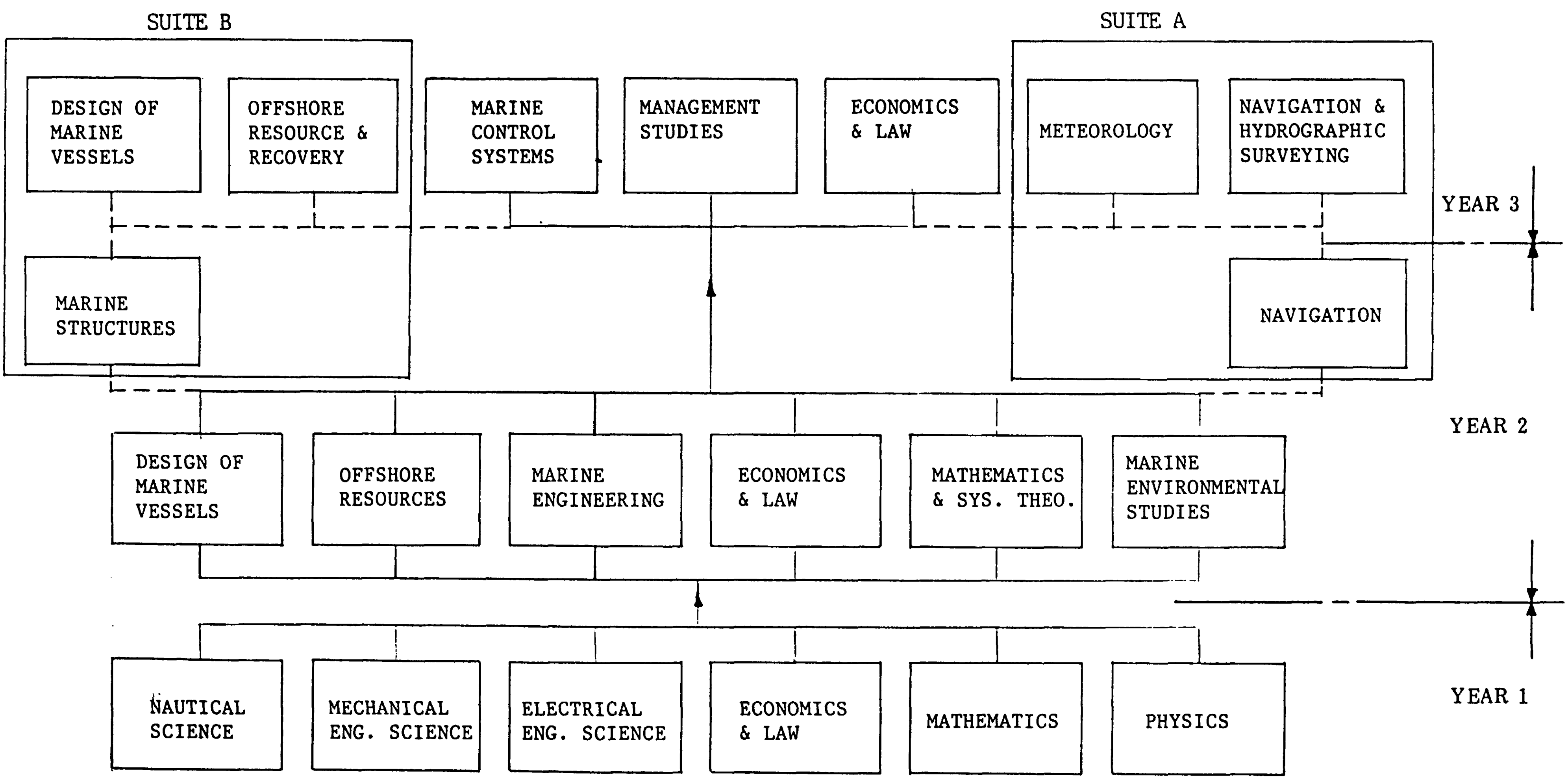


Fig.8 Course Structure of B.Sc in Nautical Studies (Sunderland)

disciplines but also receive a high proportion of overseas students. Table (9) gives the all the available courses in Offshore Engineering and related field and several of these courses will be discussed in detail.

2.4.1 University College London

The Mechanical Engineering Department of UCL has been concerned with teaching and research into advanced marine orientated topics for several years, starting with undergraduate and MSc courses in Naval Architecture since 1968, and subsequently with the MSc in Ocean Engineering since 1972.

The one year full time MSc course in Ocean Engineering emphasizes the structural, dynamic and materials considerations which arise in the design and operation of moored and bottom supported ocean installations. In its application to design, the course currently concentrates on the needs of the offshore oil industry since this is the main market for its graduates. Furthermore, since the course is aimed towards the design of structures for deep hostile waters, many of the most demanding facets of offshore work are covered. A useful and relevant training, however, is also provided for those embarking on work in offshore engineering other than in the oil and gas industry.

In the first half year, the course builds on a fundamental background in stress analysis, materials, hydrodynamics, and random

Table 9 : Universities and Polytechnics Offering Postgraduate Courses in Offshore and Related Technology

University	Course
Cranfield	M.Sc in Offshore Structures, M.Sc in Offshore Engineering, and M.Sc in Underwater Technology
Liverpool & Manchester	M.Eng and M.Sc in Maritime Engineering
Liverpool	M.Sc in Oceanography
Newcastle	M.Sc in Offshore Engineering
Robert's Gordon Inst. Tech.	Diploma in Offshore Engineering and Diploma in Offshore Materials and Corrosion Engineering (in conjunction with Newcastle Polytechnic)
Southampton	M.Sc in Oceanography
Strathclyde	M.Sc in Marine Technology
University College London	M.Sc in Ocean Engineering
North Wales	M.Sc in Physical Oceanography

processes; these subjects lead to lectures on, for example, loading and response of offshore platforms, structure/foundation interaction, design of submersible structures, response of moored and tethered buoyant units, steel and concrete environment, design criteria for fixed and floating platforms. The lectures are complemented by coursework and design studies. There are also multi-disciplinary lectures in maritime studies, including marine geology, maritime law, economics and diving physiology.

A project occupies much of the second half year which is primarily a research and development study involving a specific problem posed by industry or highlighted by the activities of the London Centre for Marine Technology (with which the course interacts closely).

Industrial input to the course takes the form of individual contacts in project work and seminars by outside speakers. In addition, each year a one-week field trip to Scotland has been organised for visits to be made to platform and rig fabrication yards. A one week diving course is also arranged, in order to enable students to appreciate at first hand the difficulties of performing inspection maintenance or constuction work underwater.

2.4.2 Robert Gordon's Institute of Technology

Since 1973, the School of Mechanical and Offshore Engineering has operated a course of Offshore Engineering, after consulation with the oil industry and it was approved by the Scottish Education

Department and by the Scottish Technical Education Council (SCOTEC) which was the awarding body until 1979. Since then the course was approved by the Council for National Academic Awards (CNAA).

The course is postgraduate in level and has a full-time structure of one academic session lasting 34 weeks. Over the years, the course has evolved and developed to meet the current and future needs of the North Sea industry. The identification of the needs are gauged from the industrial seminars, the external examiners and direct contact with the oil industry. As a direct result of the course and industrial developments, it became evident that a demand existed for a sister Postgraduate Diploma in Offshore Materials and Corrosion Engineering. In associated with Newcastle Polytechnic, the first run of this new course was in 1980/81, being a direct spin-off from the Postgraduate Diploma in Offshore Engineering.

The Postgraduate Diploma in Offshore Engineering course consists of seven subjects plus a module on survival training. The course material is presented by lectures, seminars and project activities as shown in Table (10). Industrial specialists contribute to the programme of lectures and seminars. Industrial visits are integrated into the course structure and students are required to carry out a project on an individual basis.

2.4.3 Cranfield Institute of Technology

The Postgraduate course in Offshore Structures was established in 1974 at the College of Aeronautics for the purpose of training

Table 10 : Course Structure of the Postgraduate Diploma in Offshore Engineering (RGIT)

SUBJECTS	1st Term (12)		2nd Term (11)		3rd Term (11)		Total Hours per Week	No. of Terms	Total Hours per Session
	Lecture/ Tutorial	Project/ Field Work	Lecture/ Tutorial	Project/ Field Work	Lecture/ Tutorial	Project Field Work			
Safety and Survival	32						32	1	32
Oil & Gas Production Technology	5		5				5	2	100
Drilling Technology	4		4	20*			4/20*	2	100
Geology & Reservoir Engineering	3½		3½				3½	2	70
Offshore Materials Technology			5		5 hours for 6 weeks		5	1	50
Offshore Structures			5		Tutorials/		5	1	50
Planning & Control of Offshore Operations	5				Seminars/		5	1	50
Diving & Underwater Operations	5				Indus-trial Visits		5	1	50
Project Tutorials etc				2		20 for 7 weeks	2/25	2	162 30
Total	22½		22½	2	5	20		Total	694
Total/week		22½		24½		25			

* One week only

engineers and research specialists in applied analysis techniques related to the exploration and development of the oil and gas industry.

The MSc course consist of one term of examinable lectures followed by three terms of research, culminating in a thesis. Both the lecture courses and research topics are directly relevant to actual problems experienced by industry and in many cases the thesis may form a basis of the graduate's first appointment. The structure of the MSc in Offshore Structures is given in Table (11).

Apart from the above-mentioned course, two other courses are also conducted in this Institute:

1. MSc in Offshore Engineering
2. MSc in Underwater Technology

Both the courses have the same format of structure and assessment as the MSc in Offshore Structures.

2.4.4 University of Newcastle upon Tyne

The establishment in October 1975 of the School of Marine Technology at the University of Newcastle upon Tyne brought together the Departments of Marine Engineering, and Naval Architecture and Shipbuilding with their associated ocean engineering interest. This year (1986), the School will be expanded with the inclusion of the Department of Offshore Engineering. The School, with over two hundred undergraduate and postgraduate students, and a large

Table 11 : Course Structure for MSc in Offshore Structures (Cranfield)

Term 1 : Examinable Courses (October to December)

1. Ocean Wave Hydrodynamics
2. Probabilistic Theory and Random Vibration
3. Structural Dynamics
4. Structural Analysis of Stability and Finite Elements
5. Materials for Offshore Structures

Terms 2 and 3 : Non-examinable Courses (Jan. to September)

1. Dynamic Analysis of Offshore Structures
2. Hydrodynamics
3. Design and Analysis of Shell Structures
4. Structural Optimisation
5. Stability and Postbuckling of Structures
6. Stochastic Theory and Random Processes
7. Fatigue of Offshore Structures
8. Design Principles

Note: In the second and third term, a student is required to work on a project which is 75% of the total assessment.

academic, technical and supporting staff, represents a substantial committment by the University to the development of teaching, research and associate work in marine technology.

The School of Marine Technology will begin its first MSc in Offshore Engineering in October 1986. This course consists of two ten-week terms of formal study followed by four months of devoted to a research project. The main subjects that will be undertaken by students include marine structures, marine design and offshore engineering. The amount of time allocated to formal lectures, tutorials, seminars, or supervised coursework varies a little from subject to subject but in a typical week a student may expect to spend on average:

1. 12 hours in formal lectures, and
2. 10 hours in tutorials, seminars, coursework or recommended reading.

CHAPTER 3

GENERAL DESCRIPTION OF OFFSHORE JACKET PLATFORMS

3.1 INTRODUCTION TO TYPES OF OFFSHORE PLATFORMS

Requirements for education and training of engineers that are to have careers in the offshore field can be better appreciated following a study of one aspect of their work. The aspect chosen is that of the preliminary design of an offshore production platform.

Offshore production operations present a unique set of engineering and operating problems compared with operations conducted on land. Developing fields offshore requires larger investments because of higher drilling and producing costs, transportation and logistical problems, and the need for a platform base on which to conduct the operations.

The most obvious condition that sets offshore operations apart from those on land is the water itself. The offshore environment can range from shallow inland lakes and protected bays to deep, unprotected seas and oceans. Most operations offshore are conducted in water depth less than 300 ft (91 m); however, operations in water depths greater than 1000 ft (305 m) are now occuring and will become more common with the advent of deepwater technology although there are limits to the water depth below which oil fields exist.

A platform perhaps fixed, tethered or articulated must be constructed to support operations offshore, and special consideration is given to the site-specific development and environmental conditions when designing the platform decks and structure. Over the past dozen years offshore oil platforms have increased in their size, type, technical complexity and cost.

3.1.1 Fixed Structures

The deck structure which carries the offshore production equipment is usually on top of one of two types of the fixed support namely a steel jacket or a concrete gravity platform. The steel jacket is a lattice structure piled into the seabed while the concrete platform is more solid and secured to the seabed by its own weight when flooded. Even though the decks used for both types are similiar, the structures are different in material construction and float out. various environmental conditions.

The steel jacket was first developed for use in the Gulf of Mexico, although, as the most common type of structure, it has been used in virtually all offshore areas. This type of structure is composed of the jacket and piles, with the jacket supporting the weight of the decks and adding stability to the structure, and the piles securing the jacket to the ocean floors. The advantage of a steel jacket is that it is generally less expensive than the other bottom supported platforms while remaining stable for operations in most environments.

The concrete gravity structure was pioneered for hostile environment such as the North Sea. This structure is secured to the ocean floor by its own weight. The advantages of a concrete gravity structure include greater stability, reduced installation time, lower costs for maintaining the structure below sea level, and oil storage facilities. Because of the massive bulk this type of structure is more stable and durable, particularly in hostile environments. Also, because of the nature of the concrete towers and cylinders, costs of maintaining the structure below the sea level generally are lower than those required to maintain the steel jacket. The main disadvantage of using concrete gravity structures is that they have turn out to be extremely expensive to build compared to other bottom supported alternatives.

3.1.2 Deepwater Structures

Offshore exploration and development is trending toward more hostile environments and deeper water, and innovative structures are being designed and utilized to meet these new challenges.

Platforms that sit on the ocean floor become cost prohibitive at water depths greater than 1600 ft (488 m). They also reach fatigue limits because natural periods are close to wave energy peaks. Both cost escallation and fatigue limits occur more or less together and are at approximate water depths of about: 500 m in Gulf of Mexico and 350 m in North Sea. Thus structures specifically suited for deep water have been designed. Two such structures are the tension leg platform (TLP) and the guyed tower platform (GTP).

A TLP is basically a semisubmersible hull anchored to sea bed templates by tendons that are maintained in tension to maintain the hull's position vertically and to permit lateral movement up to a percentage of water depth. The lateral movement is acceptable and self correcting when the lateral forces die down. Provision is incorporated for planned renewal of the vertical moorings. The securing point for each connector is required piled into the seabed. The advantages of a TLP include its relative insensitivity to water depth and relatively quick installation and abandonment features. Once the platform is no longer needed for a particular operation, the legs are unlatched at the ocean floor and he platform may be relocated to another field. A prototype of the TLP is being operated successfully by Conoco Inc. in the North Sea's Hutton field.

A GTP is basically a slender steel tower fixed at the seabed and held in position at intervals by guys secured to the seabed as might be a mast. Some tranverse compliance exists. It generates a minimum of hydrodynamic forces and can be used in somewhat deeper water than fixed structures without the same exponential cost increase. A one-fifth scale model of the GTP was installed and successfully tested by Exxon in 1975 in the Gulf of Mexico. This testing concluded that the structure was feasible for use in deep water and that it could withstand hostile environments such as the North Sea. In 1983, Exxon installed a guyed tower in 1000 ft (305 m) of water in the Gulf of Mexico, where it is now being operated routinely.

Of all the previously mentioned type of platforms, only the conventional fixed steel jacket platform will be considered in this study. This type of platform has proven to be the most dependable, cost-effective and efficient support systems presently available to allow offshore drilling and production operations to be conducted above-water environment such as in Malaysian waters.

3.2 HISTORICAL DEVELOPMENT OF OFFSHORE JACKET PLATFORMS

To appreciate the accomplishments of the offshore industry, it is desirable to review the history of offshore steel jacket platform construction.

The earliest platform ever to be constructed offshore begin in 1890 near Summerland, California; utilizing wooden piers extending to about 150 m off the shoreline and wooden platforms were erected to support the derricks and necessary producing equipment. Following this, drilling took place from structures constructed in several inland lakes and in Lake Maracaibo. In those days, the technical problems were modest. Since then, the industry has evolved and expanded that the number of offshore producing platforms now approaches 10,000 worldwide. A detailed history of the development are given in Reference (9), (10), (11) and what follows are the most impressive only.

In 1937, an offshore platform was built in the Gulf of Mexico placed in 4.3 m of water about 1.6 km from the coastline. This platform was the first to be constructed in the Gulf in an area remote from shore.

After World War II, in 1946, the first steel jacket platform was installed in 4.3 m of water and approximately 8 km offshore. This platform was designed to withstand hurricane winds of 67 m/s and a maximum wave height of 5.5 m.

In 1947, a platform was erected and placed in open water, out of sight of land, off the Louisiana coast in 6 m water depth.

The earlier platforms were supported by numerous small pilings. By mid 50's, the average pile size had increased to 76 cm in outside diameter, thus requiring fewer piles and allowing a more opened or streamlined bracing pattern. In 1955, the first platform in over 30 m of water was put into operation with the introducing of skirt piles which are around the vertical members driven through guides.

Offshore exploration and exploitation activities continued to go into deeper and deeper water. In 1967, a platform was placed in 104 m of water, the first ever being ventured over 100 m depth of water. In the early 70's, two platforms were installed in 114 m of water, one in the Gulf of Mexico and the other 208 km off the Louisiana coast.

In 1976, Hondo, a pile-supported steel jacket type platform was installed in 260 m of water in the Santa Barbara Channel, off California. A year later, the world witnessed the installation of the tallest, self contained, drilling and production platform, Cognac, in water of average depth of 311 m in the Gulf of Mexico on the continental slope about 100 km southeast of New Orleans, Louisiana.

The search for offshore hydrocarbons has in the latest years resulted in further interesting resources discoveries in other parts of the world including the North Sea, South America, South East Asia, and Australia.

The first North Sea oil was discovered in the Danish sector in 1966 but was not of commercial value. The Ekofisk oil field, located in the Norwegian waters, was the first major oil discovery, and it resulted in the subsequent large scale activities of exploration and discoveries of oil fields in other regions in the North Sea.

In 1982, Magnus, the world's heaviest single piece platform was installed in the North Sea's most northerly oil field. The massive 212 m high tower which was floated to its location, weighs 40700 tonnes. This platform is not only remarkable for the size alone, but also stands at the centre of a project costed at more than £1300 million.

For the last 40 years, offshore jacket technology has been developed successfully from simple structures of 50 tonnes weight in very shallow water to complex structures of up to 60000 tonnes in 300 m water depth. There is no indication that 300 m represents an upper limit technically but this depth does represent an approximate limit beyond which other types of structures may be economic.

3.3 GENERAL DESCRIPTION OF OFFSHORE JACKET PLATFORM

Offshore jacket platforms consist of three components (Fig.9):

1. The drilling and operating facilities, often identified as the topside equipment and sited on the deck structure,
2. Jacket or tower, and
3. Foundation (mainly piling).

3.3.1 Topside Equipment

Included in the topside plant are the drilling rigs, oil and gas processing equipment, living quarters, cranes, helipad and a flare tower (to burn off gas whenever it cannot be used), and utilities. There are several type of topside facilities platform; depending on the functional criteria (Fig.10). In deeper water it is usual to accept that all functions above are located in a multilevel structure called a self-contained platform. In shallow water, cost factors allow separate platforms which reduce individual platform composure to risks such as fire and explosion. Where several platforms serve a field in deepwater, personnel not on duty may live in a distinct accommodation module often a dedicated semi-submersible. This vehicle may have a gangway to one platform and use helicopters to access others, thus reducing the risk to personnel and less restriction on them off duty. It is the tradition of offshore operators to have separate platforms for drilling, production and accomodation in shallow water.

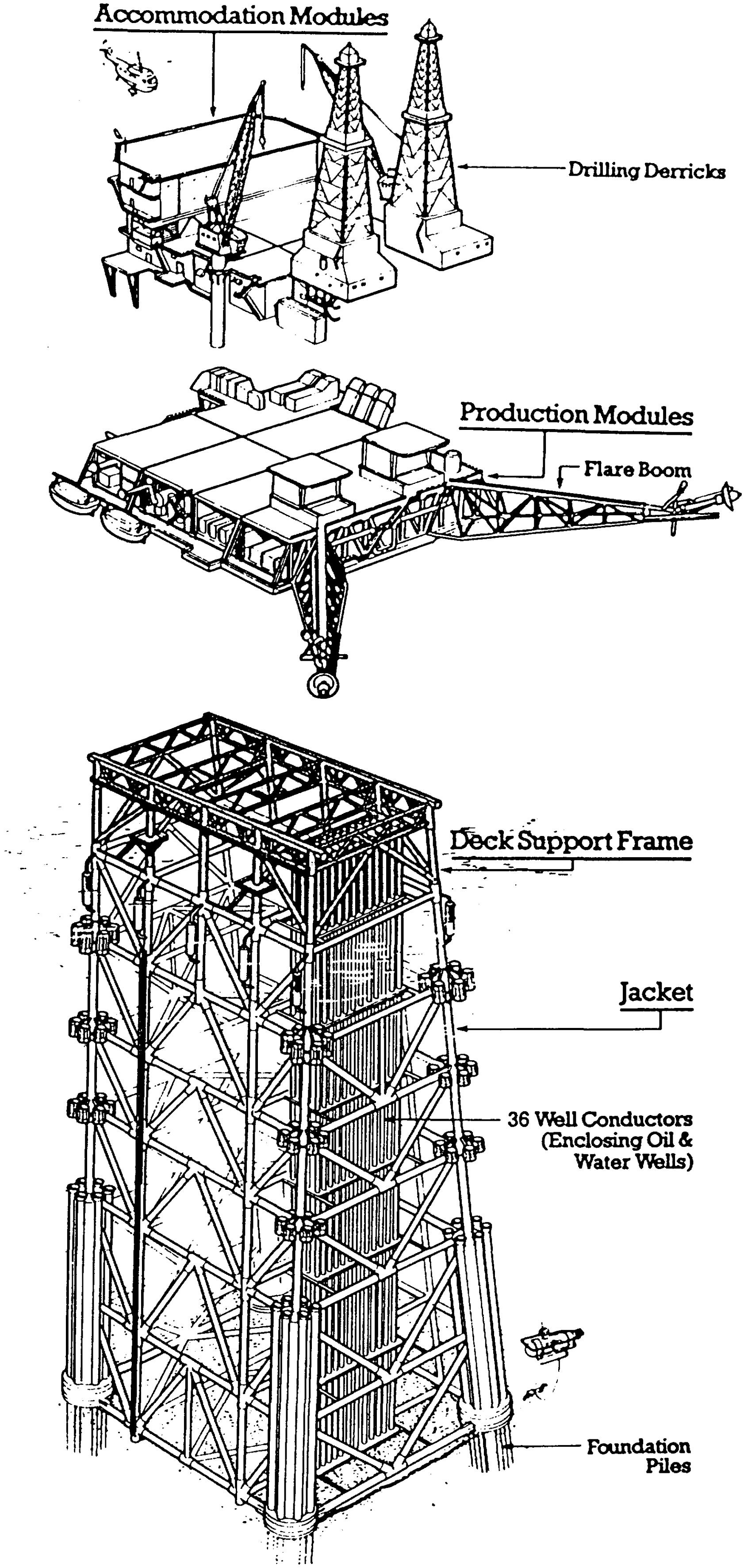


Fig.9 Typical Steel-Piled Drilling/Production Platform [31]

Topside weight varies from 5000 to 30000 tonnes and has a total floor space area of 8000 to 40000 square metres, much of it dedicated to crew quarters. These massive superstructures must be positioned above the crest of the highest wave expected to come once in 50 or 100 years [44].

3.3.2 Jacket

Steel jackets can be divided into further broad catagories; 'template' and 'tower' structures. Generally, a template structure has a rectangular planform and has eight legs which are not vertical; from the plan view rectangular size at 3 to 4.5 m elevation (seadeck level), the legs flare out, or are said to be 'battered'. Tower structures have a squarer planform and have relatively few large diameter, non battered legs and fewer diagonal braces of larger size than those used in rectangular template structures. Fig.(11) shows the variation of weight of the jackets varies with depth of water.

There are several types of braces (K, X, horizontal, diagonal) that can be used for stiffening the legs of the platform as shown in Fig.(12). These bracing systems perform several functions including:

1. Assist in transmission of the horizontal loads to the foundation.

2. Provide structural integrity during fabrication and installation.

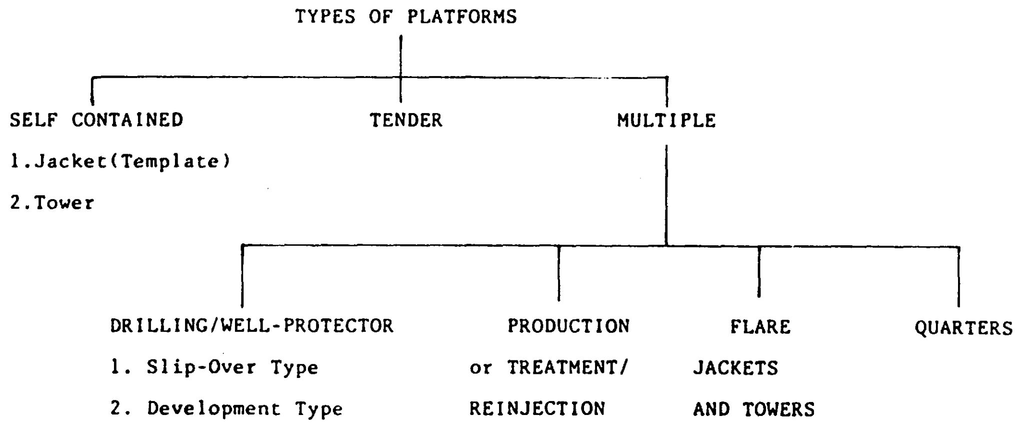


Fig.10 Type of Offshore Jacket Platforms

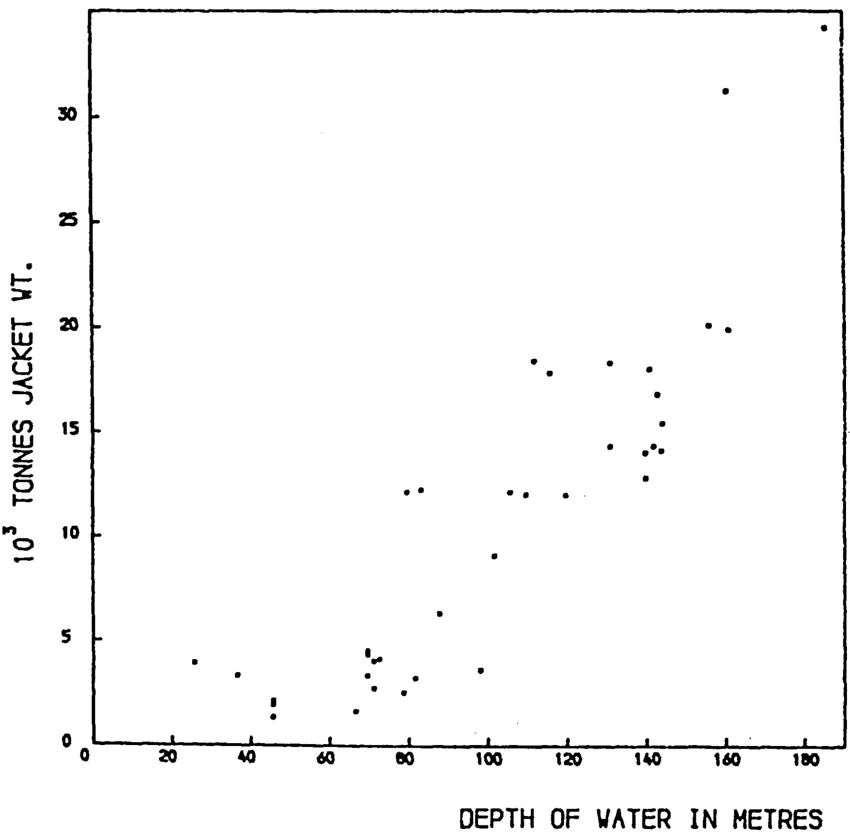


Fig.11 Jacket Weight versus Depth of Water

3. Resist racking motion of the structure.

4. Support the corrosion anodes and well conductors; carry the wave forces generated by these elements to the foundation.

The choice of framing should offer the best horizontal and torsional resistance to the particular wave and current forces involved. Optimization of the bracings passing through the still waterline has to be taken into account to ensure maximum wave tranparancy and sufficient redundancy in the case of impact with a vessel.

3.3.3 Foundation

The supporting structure must have a very secure foundation. In sea bottom soft soils, it may be necessary to drive piles more than 150 m into the sea floor before adequate support is achieved. The overall length of the pile driver, including the pile follower between the pile and the pile driver above water can therefore exceeds 330 m and call for handling hundreds of tonnes of material in one continuous assembly.

The pile foundation for a steel platform usually consists of several group of piles, frequently four. Each group of piles is driven through one of the large diameter legs with each pile subsequently serving as a conductor through which a well may be drilled.

The size of the piles and the depth to which they are driven vary, of course, from one structure to another depend on the number employed, the loading anticipated and the subsoil conditions. Typically, though, piles of outside diameter in the range of 0.5 to 1.5 m with wall thicknesses in the range of 12 to 25 mm are not uncommon, with these being driven to depths of 60 m or more [9]. In certain cases where very soft soil conditions exist, additional skirt piles may be used. These are piles drven around the base of the structure and attached there in order to provide further support.

3.4 CONSTRUCTION AND INSTALLATION OF JACKET PLATFORMS

An offshore platform is a specialised structure uniquely developed to serve a very special purpose. The concept and design of an offshore platform must suit the condition of the field and may be influenced by the method of construction in the fabrication yard and the method of installation at the offshore site. Architectural or aesthetic matters are scarcely considered although appearance will differ depending on location. More northernly locations have much more protective cladding for cold weather. An interesting development may be the need to ensure how the structure may be removed without environmental damage when the field is exhausted.

Most of the fabrication takes place in a construction yard onshore. The components are prefabricated into the largest units that can be economically and quickly transported from the fabrication yard to the offshore site. Prefabrication allows for a minimum amount of construction time at sea to minimise the required weather window.

The largest structural component of a typical steel platform is the jacket; it extends from the ocean floor to above the water surface. The legs, or columns, are open tubular members and are often battered. Thus, special plans have to be made by the fabricator to ensure the capability of handling a jacket once assembly has been completed. In addition to the size , the weight of the components also adds difficulties.

The method of installation of a fixed jacket offshore platform at site involves three distinct phases:

1. Jacket Installation
2. Pile and Conductor Installation
3. Deck Section Installation

3.4.1 Jacket Installation

For shallow water, the jacket is completely fabricated in one piece, carried to the location on a cargo barge, picked up and set on the bottom by a derrick barge (Fig.13). For all except shallow water, the most frequently used installation technique for jackets is launching from a barge at the location (Fig.14).

The latest generation of water depth record breaking platforms are made of multi-part jackets which are joined together, either horizontally (Fig.15), or vertically (Fig.16) at location.

When deepwater jackets are too heavy for available launching equipment to handle, the concept of self-floating jacket is a viable alternative (Fig.17). The self-floatation structure is characterised by the legs which have sufficiently large diameter that adequate 'built-in' buoyancy is provided, thus enabling it to float at a relatively shallow draft, although removable buoyancy chambers are usually needed as well.

3.4.2 Pile and Conductor Installation

The jacket is deballasted selectively at its location until it assumes the proper level in water. As soon as the jacket has been set on the bottom, a pile is inserted in each of the jacket legs and driven to the desired penetration. For jacket with skirt piles, the main piles are driven first, followed by the skirt piles and finally the conductor tubes. The conductor tubes are driven from 30-60 m into the ocean floor through the conductor tube guides fabricated into the interior of the jacket framework.

After all the piles have been driven to the desired penetration, the annular spaces between the piles and the inside of the guides or legs are filled with cement grout. The grout will produce a permanent bond between the piles and the guides, thus creating a single, rigid structure. If the design calls for skirt piles, these are usually grouted after the deck substructure and deck modules are in place.

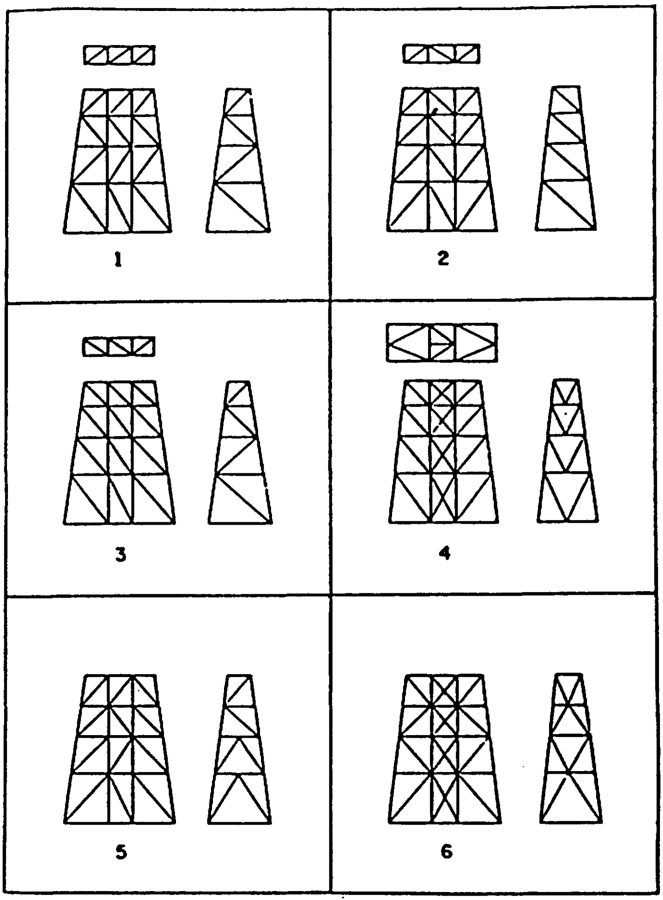


Fig.12 Commonly Used Jacket Framing Plans [9]

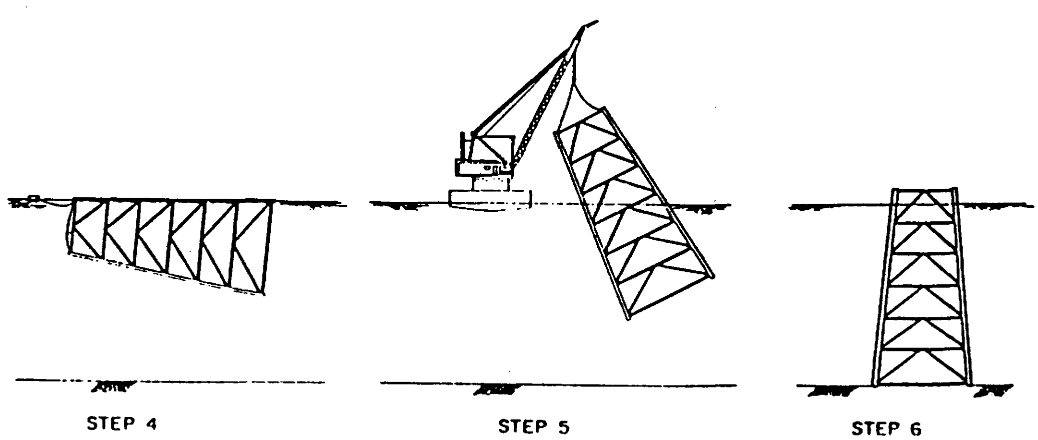


Fig.13 Installation of Jacket by Launching [11]

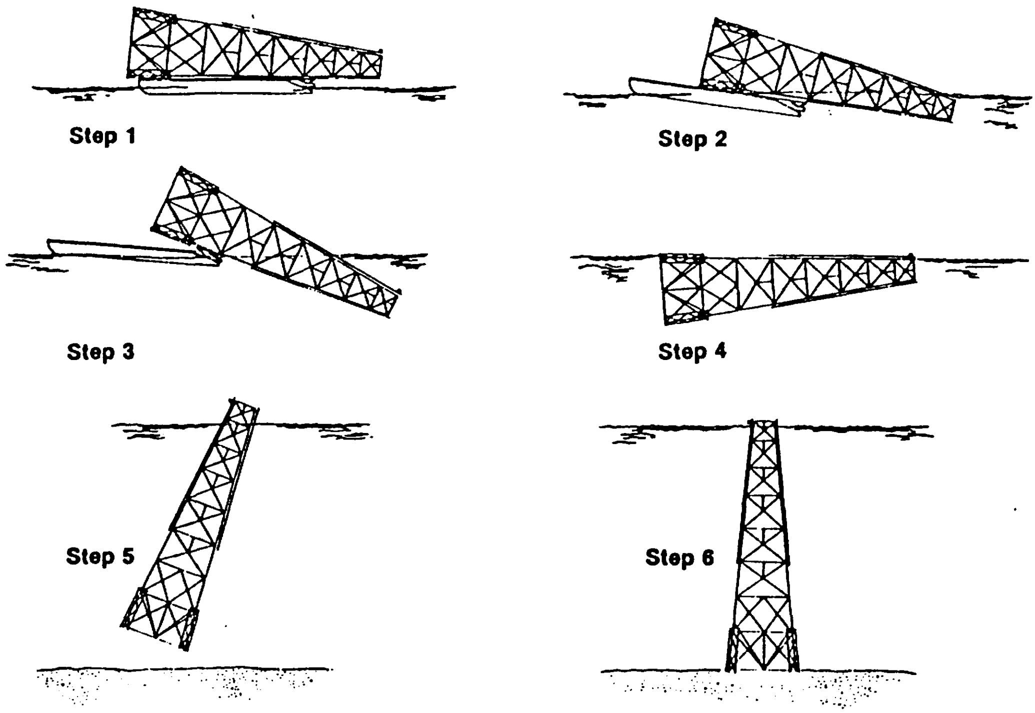


Fig.14 Installation of Deep Water Jacket by Launching [11]

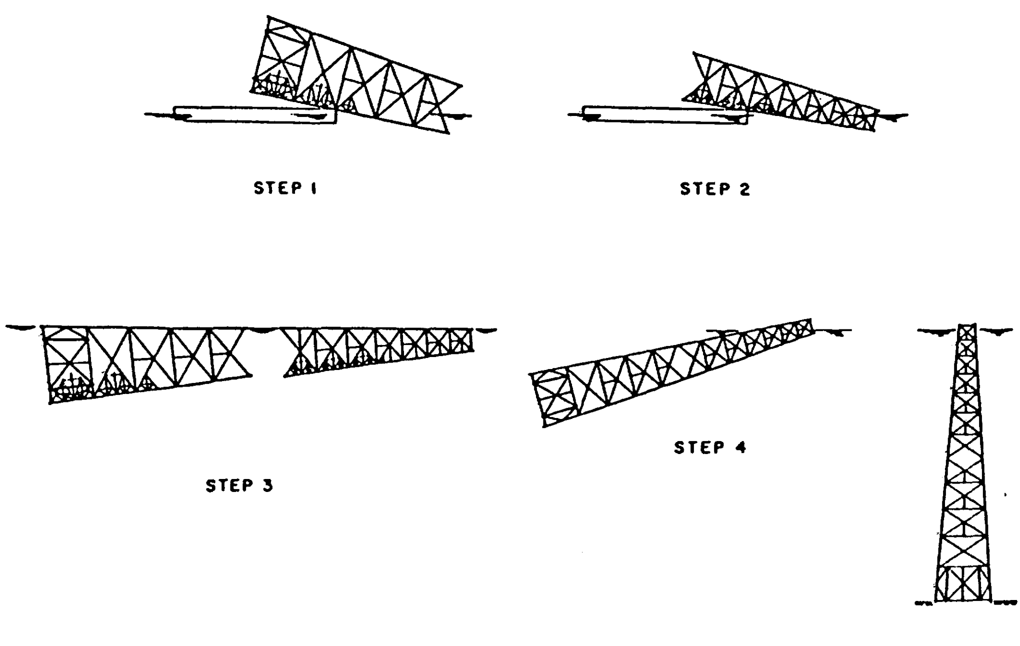


Fig.15 Horizontally Connected Sectionalized Jacket [11]

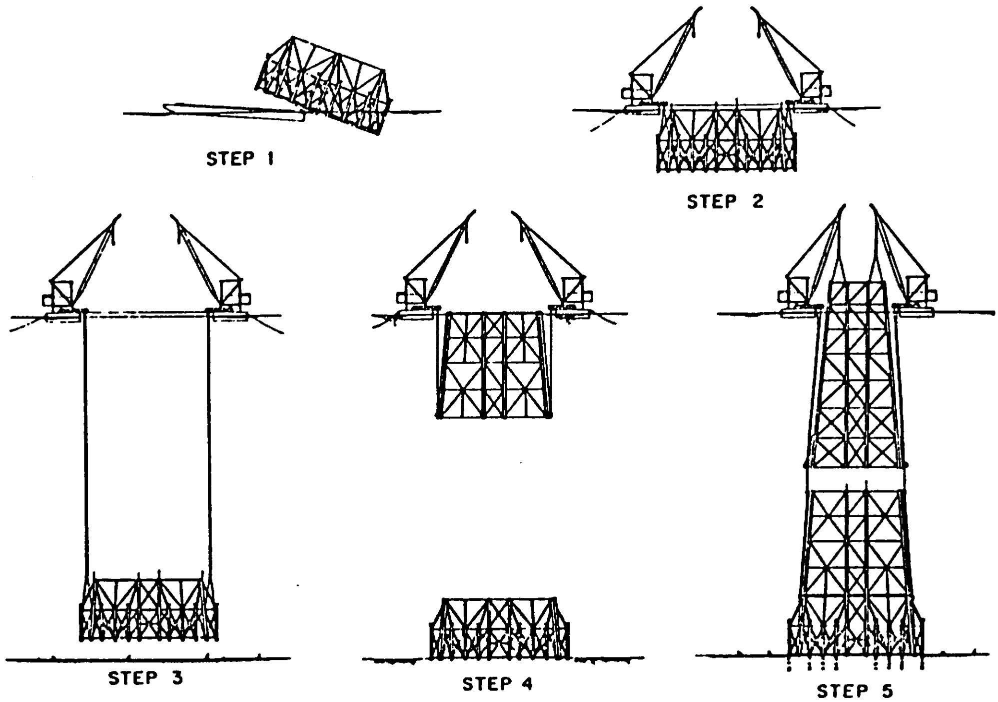


Fig.16 Vertically Connected Sectionalized Jacket

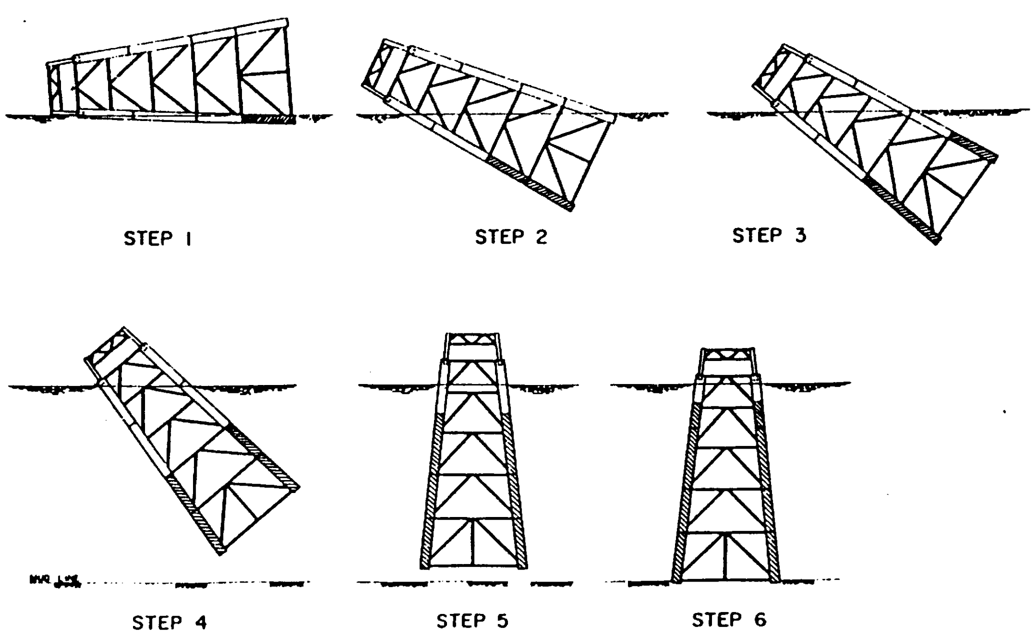


Fig.17 Installation of Self-Floating Jacket

The piles ends extending out at the top of the jacket legs are cut off in such a manner that the deck substructure will be level after installation; even if the jacket top is not level.

3.4.3 Deck Section Installation

The deck substructure is fabricated and transported in its normal upright position. Installation of temporary erection bracing may be needed to avoid overstressing of the framework during conveyance from the fabrication yard skid runners to the transportation barge skid runners or lifted into its final position offshore. The lower ends of the deck substructure columns are made cone-shaped so that they may be easily stabbed into the pile ends protruding from the top of the jacket legs.

The installation of the modules at the offshore location is done by lifting it into its position by a derrick barge. Sometimes two derrick barges are necessary to pick up large, heavy modules.

In cases where the topside structure is of the Hideck type (a complete topside facility), it is transported on a barge fully equipped to the previously installed jacket at a sufficient elevation for the deck to be lowered onto the jacket. The operation requires only a single brief weather window, and no crane is needed as the barges position the structure above the jacket. The deck equipment and the whole structure itself can be designed more efficiently for towout and installation without the destabilishing weight of the deck. Barges are now available which can transport a Hideck structure weighing 25000 tonnes at 30 m above deck level through summer storm conditions.

3.5 DESIGN CONSIDERATIONS

The general requirement of offshore platforms are similar to any other industrial structure with the very special additional attention to be taken into account that the offshore structure is constructed in one area and installed in another. Special attention is also given to the site-specific development and environmental conditions when designing the platform decks and jackets. Among various stages in the design of fixed offshore platform includes:

1. Identifying the purpose of the platform.
2. Determining the operational criteria.
3. Evaluating the environmental and foundation criteria to which the platform is to be sited.
4. Making the preliminary design proposals with major emphasis on the fabrication and installation method to be employed.
5. Cost effective studies; providing a satisfactory return on the investment.
6. Determine the sizes and details of the chosen configuration to carry required loads and environmental forces.

7. Evaluate the designed structure's capability to withstand the loading associated with transportation to and installation at the offshore site.

The purpose of the platform to be constructed is to support operations offshore on a deck having a prescribed minimum working area and carrying a prescribed minimum weight.

Some of the operational criteria to be identified include the number of wells to be drilled, the type of producing equipment, and the mode of hydrocarbon transportation. These criteria determine the size and number of platform decks needed to contain the necessary equipment and thus determine the weight to be supported by the jacket.

Environmental conditions are identified when designing the structure to examine the effect that oceanographical and meteorological forces may have on the structure. These forces are imposed by water depth, wave, wind, tide or ice conditions. Soil and ocean floor characteristics are also investigated to determine the criteria for designing the structure's foundation in earthquake zones, soft or hard ocean floor conditions, and, in arctic regions, ice scour conditions.

With the above mentioned information made available, preliminary designs can be developed bearing in mind the method of construction and installation intended to be utilised. Of these various preliminary designs, some may easily be rejected as economically unfeasible or impractical from construction or installation considerations. Thus, the reliable and cost effective design of the structure requires the designer to consider four basic factors of a practical nature: material selection, structural configuration, constructability and erectability.

Considerations associated with material selection include the strength, failure and fracture characteristics needed to satisfy the design criteria at all locations within the structure. Welding characteristics inherent in the material are also considered in the selection process.

Determining of the configuration of the structural components is related to both overall framing and design details, and is governed mainly by load path considerations for the different design cases. Redundancy is also a factor in the selection of framing patterns. Any frame structured supported by more than three piles has a redundant pile foundation. Similarly, the framing of the most the most of fixed offshore structures has some redundancy. Careful selection of the configuration can increased the effectiveness of the redundancy and stiffness while minimising areas exposed to wave forces in the in-place situation and congestion at tubular joint connections, thus improving overall realiability.

Once the selection of the configuration of the structure and estimation of the sizes of the various members is completed, the design cycle is gone through again. Revised computations of the operational and the environmental loads are made, the foundation requirements are again evaluated and, finally, the various structural member sizes are determined. The overall process cycles among these major aspects until adequate and safe design, meeting all the criteria, is evolved.

After the preliminary structure is completed, it is then necessary to begin the analysis of the fabrication and installation arrangements. This includes a review of the construction procedures, taking into account the stresses which will be encountered for lifting, launching, floating, hydrostatic pressure, and other items. Whatever towing and installation arrangements are required, certain general criteria have to be considered:

1. Stability with due regard to free surface water effects, ballasting procedures, load distribution, relevant environmental loading and the consequences of likely impacts.

2. The loading effects during these operations can be sustained without impairing the subsequent performance of the structure.

3. Appropriate configuration of mooring or towing lines and their effect on the structure and/or transporting system.

4. Appropriate selection of a suitable towing route with adequate water depths, available data on currents, winds and weather during some define period.

5. Careful planning of all aspects of marine operations having

due regard to the weather, logistical and practical problems of carrying out all phases of operations; effective contigency plans should always be available and effective briefing of all personnel involved is vital.

The communication arrangements linking up individual vessels offshore with command centres are important during transporting the structure to its site.

In addition to establishing the design criteria the basis of the design must also be established. Traditionally, most engineering design has been performed following the practices recommended by British Standards or other National codes. Unfortunately, these specifications were developed with other type of structures in mind such as buildings and bridges, and perhaps do not apply to all phases of the design and construction of offshore structures in an open sea environment. It must be stated of course that in any oil industry situation a wide range of the American Petroleum Institute Codes apply.

In the early days of offshore oil work, several marine classification societies such as Bureau Veritas, Lloyds Register, Det Norske Veritas and American Bureau of Shipping adapted their existing codes to suit the offshore oil industry. A good deal of experience has now been gained offshore and modern codes of practice have been able to incorporates this experience, much theoretical work and the best of previous codes of practice.

The designers working in the offshore field needs very wide understanding of which codes of practice must be followed in any particular situation. Major oil companies based on their own experience have drawn up lengthy recommendation for all aspects of engineering work which must be met for their approval. In addition the codes of practice of the certifying authority must be followed which for the Norwegian sector of the North Sea is Det Norske Veritas. Then follows the requirements of government agencies with particular interest perhaps in safety and rescue of which some regulations will be international and any special requirements of insurance underwriters.

The task of designing an offshore jacket platform involves much information and groups. Good management is essential and the work may be a frontier of existing technologies. The technologies involved is summarised in Fig.(2).

CHAPTER 4

OPERATIONAL CRITERIA ANALYSIS

4.1 INTRODUCTION TO OPERATIONAL LOADING

The initial design requirement for any offshore platform is that it should be able to support an equipment and personnel workload above the wave zone, and simultaneously resist the effect of the waves, currents, winds and temperatures expected at its fixed location during its intented working lifespan.

The development of a full inventory of platform weights commences with topside weight estimation very early in the conceptual design process. Again this topside weights vary significantly depending on the platform location - the water depth, environmental conditions, foundation conditions, and the platform function - the peak throughput of oil or/and gas, the type of process facilities, the number and depth of wells, the number of pesonnel to be accommodated, type and standard of the accommodation.

Since most of the load acting on an offshore platform is due to its deck and equipment weights, it is necessary to have a reliable estimate of these weights early in the design process so that preliminary design of the support structure can be made and so that the module lifting and transportation requirement can be determined.

The topside design objectives are very complex, not only does the superstructure have to fulfill the basic structural requirements of strength, serviceability and so on, many functional requirements must also be satisfied. For example, the physical layout of the process plant and facilities must follow the process flow as far as possible to avoid unnecessary duplication of piping runs, areas of differing hazard potential, cleanliness and noise level must be separated and there must be sufficient access provided for large turbine exhausts, ventilation ducts, electrical and instrument trays. There must also be escape routes and means of access for maintenance or replacement of large, heavy equipment.

Where equipment and systems are packaged in modules, problems arise in calculating the load transferred through the module support points to the deck. The distribution of the load transfer depends not only on the weight distribution inside the module but also on the relative stiffnesses of the modules and deck.

The correct determination of the individual module reactions is important because the forces are invariably large and the consequences of mistakes or gross inaccuracies can be dangerous Considerations should also be given to the effect of deflections of the structure due to these loads.

The decision whether to adopt a few large modules or a greater number of small modules will be based on detailed cost studies including onshore fabrication, offshore installation and hook-up. This studies will form one of the principal key documents which define development of the superstructure design.

4.2 PRIME FACTORS INFLUENCING THE DESIGN OF MODULES FOR OFFSHORE APPLICATIONS - COMPARISON WITH ONSHORE MODULE DESIGNS

It is important to recall some general factors which influence the design of offshore modules and which, although obvious, are often not held in due consideration.

1. Environmental conditions are usually hostile; the effect of the marine environments can produce serious corrosion problems on the machinery, equipment and structures.

2. Modifications to module layouts are more difficult and thus not welcome as compared on an onshore site. Module dimensions and positions in relation to the other modules or equipment on sea platforms are already established. If there are to be future modifications, such as improvement or adding extra equipment, they have to be defined at the beginning of the design phase and taken into due consideration. If not it could be impossible or extremely costly to make later changes.

3. Design errors should not be discovered during construction: the impact on costs and delivery times could be dramatic. Remembering that sea transportation is often not posible all year round, if shipments are not made when possible, effective delays can become very long. Equipment a week late may delay the work a year. This means strictly respecting

delivery schedules. Tighter control of design activities than for onshore projects is therefore necessary.

4. Design must be frozen early and close control be kept on a whole series of external interfaces (with the offshore transport, module contractors, procurement services, and certifying authorities) and internal interfaces (with the design departments for the various equipment or system).

5. Rationalization of weights and dimensions can be achieved easily and in less time if the supplier of the module is also the designer and manufacturer of the main module components as checks and decision making are much more rapid.

6. The regulations and standards that apply to offshore installations must be identified immediately and studied in detail to avoid unpleasant surprises during the development of the design.

4.3 TOPSIDE LOADING

The loadings of a platform can be tabulated in the following four groups of weights:

4.3.1 Dry Weight

The dry weights of a topside facilities may be divided into three broad categaries: major equipment, bulks, and topside structure.

Major equipment consist of all the equipment required for production operations, all the support utility equipment, drilling equipment and power generation.

The bulks include the piping, valves, instruments, electrical and instrument cables, fire proofing, firewall cladding, and miscellaneous support steel structures.

The topside structural steel is the steel used to support equipment, including stairwells and walkways.

4.3.2 Lift Weight

This includes the equipment skids and modules weight required to determine the type and capacity of derrick crane to be used in placing equipment on the deck. The calculated dry weight of equipment skids and modules is usually increased by 5 to 8% to account for temporary bracing steel, lifting aids and hooks.

The adjusted lift weight is then used to select a suitable crane at its appropriate maximum reach, relative to the height to be lifted.

4.3.3 Test Weight

This weight refers to the possible requirement to hydrotest vessels or piping in place offshore. The tabulation of hydrotest weight may not be required if hydrotesting during the operational life is not required periodically by local authorities.

The test weight is used only for topside structural information to determine temporary points of loading and structural allowances in the topside structural design.

4.3.4 Operating Weight

The operating weight of a platform consists of the consumable storage and the liquid inventory of vessels and piping. For multifunctional platforms, the operating load is about 1.30 to 1.35 times the total dry weight. The total dry weight includes topside structural steel [19].

4.4 FACTORS AFFECTING OPERATIONAL LOADS AND TOPSIDE PLATFORM AREAS

4.4.1 Optimization

Optimization of platform facilities can be defined as limiting the amount of equipment to that which actually required to safely meet the operational demands.

It can have a significant effect on the platform area requirements, the topside facilities weight, and the total installed cost. For example, optimizing the number of oil and gas seperator trains, the number of gas compression trains, and the selection of equipment and the utilisation of all facilities to the maximum extent possible, can result in reducing topside platform area, weight and cost by 25% to 40%.

Careful phasing of facilities can also result in reducing the platform area and weight. For example, a platform with a large drilling program can have the drilling equipment removed upon completion of drilling, leaving only that equipment needed for a workover operation. Space may then be available for the deferred equipment such as water injection or gas compression facilities. Effluent water, increasing in volume with time, may also have its facilities phased, using the space vacated by drilling facilities.

4.4.2 Operating Weight of Living Quarters

The operating weight of the living quarters consists of personnel effects and galley consumables. On large platforms, pallets of consumables may be delivered by workboat and must be assigned to the living quarters weight.

4.4.3 Operating Weight Effect of Environment

Environmental loads on offshore platform may induce significant distortion to the topside structure. This distortion, resulting in the differential vertical deflections to the reactions to be redistributed. Wind and wave loads will cause the module reactions to fluctuate. These effects is quite significant for both the module structures and the deck structure. The increase in module reactions may cause load overstressing and the fluctuating reactions caused by the wave loading will shorten the fatigue life of the deck structure and the modules.

4.4.4 Reservoir Support Facilities

The weight effect of water injection or gas reinjection depends upon the method of reservoir pressure maintenance. If seawater is used for injection water source instead of source well water from an aquifer, additional facilities are required for dearation, filtration, and chemical treatment.

If gas is being reinjected into a reservoir, the type of compressor (reciprocating or centrifugal) and the type of compressor driver will make a large impact upon the platform area and supporting utility requirements.

4.4.5 Gas-Oil Ratio (GOR)

The method of gas disposal depends on the gas-oil ratio. A GOR greater than 200 to 300 may be economical to export by pipeline to sales. Other methods are high pressure gas reinjection or flare. If gas compresion equipment is required for sales or reinjection gas, the production equipment allocation and support utilities will have very large effect on the platform.

4.5 ESTIMATION OF THE OPERATIONAL CRITERIA

Most of the topside facilities are separate sub-assemblies or modules usually designed independently, sometimes to different codes or standards of practice, fabricated in isolation from one another, often in different countries and continents. Thus, very little firm data concerning the individual weight of the modules will be available at the start of the design.

In this chapter, studies on the existing jacket platforms in the North Sea is done in order to draw some relationship concerning the topside weight and facilities. Another objective is to try to derive certain recommendations in terms of research toward designing better facilities in the future.

4.5.1 Topside Weight Estimation

Data related to seventeen different facilities, characterised in the following as A through Q, is given in Table (12). The weight given include drilling, production, and processing equipment, utility functions, modules and minor structural steel as well as miscellaneous items necessary to maintain and safeguard the platforms. Since the weight of the living quarters varies with the number of personnel to be accomodated, it is excluded from the topside weight. The module support frame weight is also excluded because this is necessary to allow comparison of the topside weight only. Note that all the seventeen facilities have the same function, that is, drilling, production and accomodation. This table also includes the oil production capacity, the gas and oil ratio, the number of conductors and the depth of water. Qualitative information about other possible platform functions are given (yes/no). Such functions being the water and gas injection.

It is worth noting that if oil production capacity alone is considered in relation to the topside weight; the weight necessary to produce one barrel of oil varies between 0.061 to 0.241 tonnes. Although it is clear that oil production capacity alone does not define the extent of platform facilities, the relationship between weight and oil production capacity is further analysed in Fig.(18).

In this figure, two characteristic plots have been used to distinguished between the northern North Sea platforms and the southern North Sea platforms. This is necessary, since the design criteria used may not be similar. The northern North Sea platforms may have to be designed more generously in order to overcome the severe weather conditions as compared to the southern North Sea weather conditions. Two lines may be drawn, the lower to bound the southern platforms and the upper line for the northern platforms.

The most significant deviation for the southern North Sea platform is Piper, which seems to be the lightest and Brae B, by concept of weight against barrel of oil per day, is the heaviest of all. This is best explained by the fact that this platform consists of twin facilities including two drilling modules, two wellheads, and two seperator and compression modules. For the northern North Sea, platform Claymore seems to be the lightest.

Within available information the weight data against production capacity plot shows a few cases apparently out of normal bounds. There may be special cases or they may indicate unnecessarily heavy

Table 12 : Functional Information of the Topside Facilities

ITEM	FACILITY	OIL PROD. CAP. (BOPD x 10^3)	GOR (SCFD/BOPD)	WATER INJ	GAS INJ	TOPSIDE WEIGHT(T)	WATER DEPTH(M)	NO. OF CONDUCTORS
A	AUK	99	101	YES	NO	7803	84	12
B	BERYL 'B'	100	1370	YES	NO	3100	120	21
C	BRENT 'A'	100	2000	YES	YES	13980	140	28
D	CLAYMORE	160	-	YES	NO	12400	110	36
E	COMMORANT N	180	500	YES	NO	10870	160	40
F	FORTIES	150	-	YES	NO	9550	106	27
G	FULMAR 'A'	180	-	YES	YES	19570	82	36
H	MAGNUS	140	-	YES	NO	27600	187	27
I	MURCHISON	150	-	YES	YES	21685	156	30
J	NINIAN SOUTH	180	-	YES	NO	23600	140	42
K	NINIAN NORTH	90	-	YES	NO	12900	140	24
L	N.W.HUTTON	130	-	YES	NO	17420	144	40
M	THISTLE	200	-	YES	YES	17220	162	70
N	MONTROSE	60	-	YES	NO	4486	90	24
O	TARTAN	75	933	YES	NO	9000	142	33
P	BRAE'A'	120	-	YES	NO	29000	103	46
Q	PIPER	250	-	YES	NO	7920	122	36

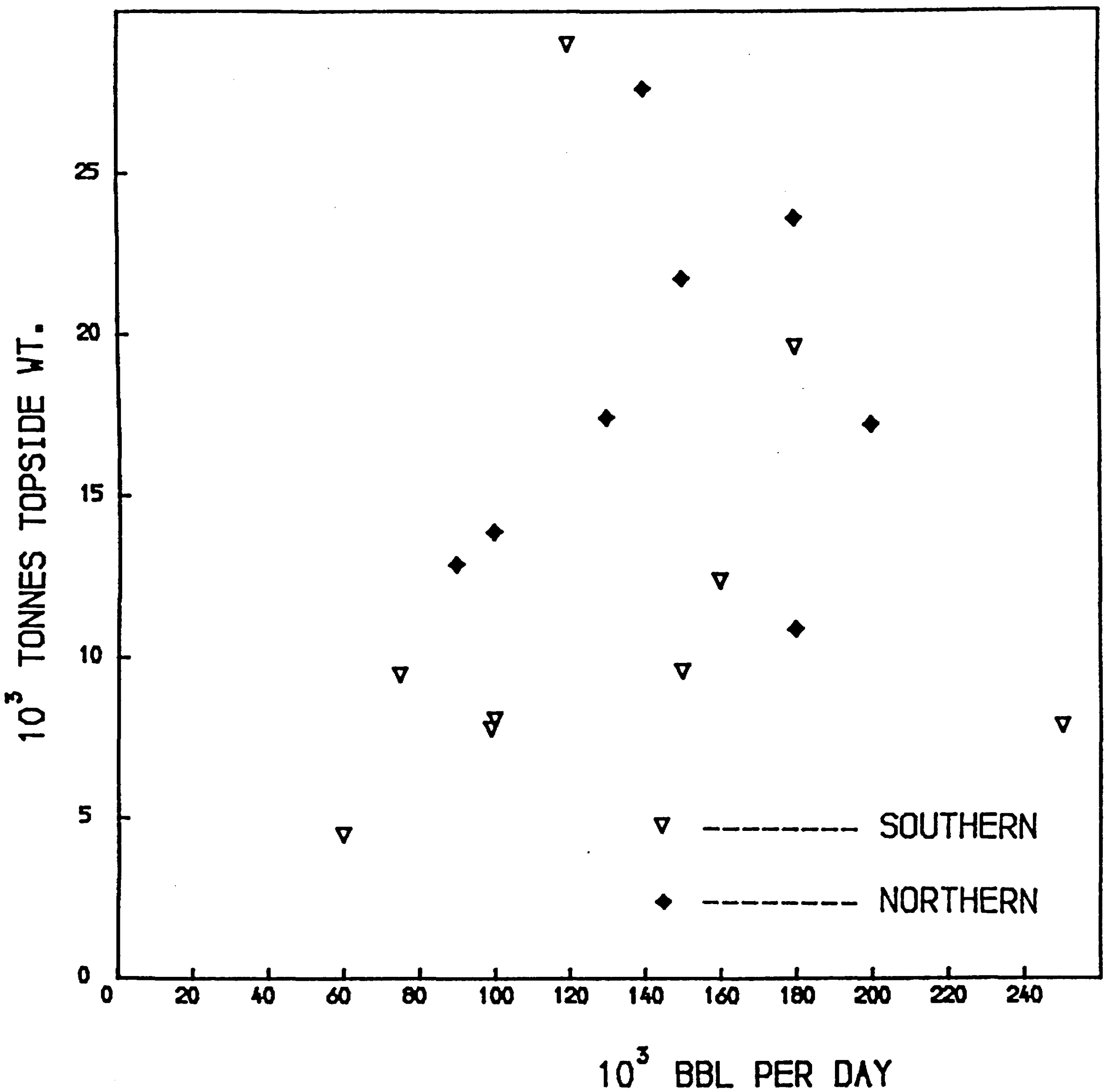


Fig.18 Weight of Topside Facilities As a Function of Oil Production Capacities

and costly installation.

In order to understand the topside facilities in more detail, several functions of the topside facilities are given in Table (13) in terms of percentage of these function weights over the total weight of the topside facilities.

The most immediate comment about this table is the limited difference between the corresponding figures. Some of the percentage deviations may be accounted for by the nature of the facility. Other conclusions are difficult to draw.

Fig.(19) shows the relationship between the module support frame weight and the topside facilities weight and Fig.(20) gives the relationship between the number of men to be quartered and the accomodation weight.

4.5.2 Deck Area

Another important requirement concerning the topside facilities and the deck structure is the required area needed for the platform. This is necessary, not only to initiate the design of the configuration of the jacket but also to analyse the concentration of the forces from the modules onto the module support frames and subsequently onto the jacket itself.

Table (14) shows the various platforms taking into account the production capacity and the deck area. Even though this analysis includes platforms that produce both oil and gas and there is a

Table 13 : Percentage Breakdown of Weights of Topside Facilities

FACILITY	SEPARATION	COMPRESSION	UTILITIES	WELLHEAD	WATER INJ.	GENERATION
CLAYMORE	19.4	19.0	*	12.1	*	20.0
COMMORANT NORTH	14.7	14.7	10.9	12.9	11.6	10.3
FULMAR 'A'	9.7	11.1	9.3	9.7	11.0	8.9
MURCHISON	*	7.0	12.6	13.7	*	10.5
N.W.HUTTON	16.9	17.4	13.9	*	*	17.2
BRAE 'A'	14.5	6.3	6.2	11.0	17.4	10.5
PIPER	17.9	14.2	*	12.3	*	14.9

* Data not available

Table 14 : Information on Deck Area and Type of Construction

FACILITY	AREA (m^2)	TYPE OF CONSTRUCTION
AUK	1720	Steel, truss deck
BERYL 'B'	2560	Cellar
BRENT 'A'	2300	Steel, plate and girder
CLAYMORE	*	Steel
COMMORANT NORTH	2158	Steel, module support frame
FORTIES	2764	Steel, integral part of modules
FULMAR 'A'	2530	Steel
MAGNUS	5700	*
MURCHISON	5544	Steel, tubular module support frame
NINIAN SOUTH	4420	Steel, truss deck integrated with modules
NINIAN NORTH	3000	Steel, truss deck integrated with modules
NORTH WEST HUTTON	1872	Steel, module support frame
THISTLE	5810	Steel, box-girder skid-beams integrated into jacket
MONTROSE	2950	Two steel decks with tanks
TARTAN	*	Steel
BRAE 'A'	3500	Skid, acts as part of jacket to form support for modules
PIPER	*	Steel

* Data not available

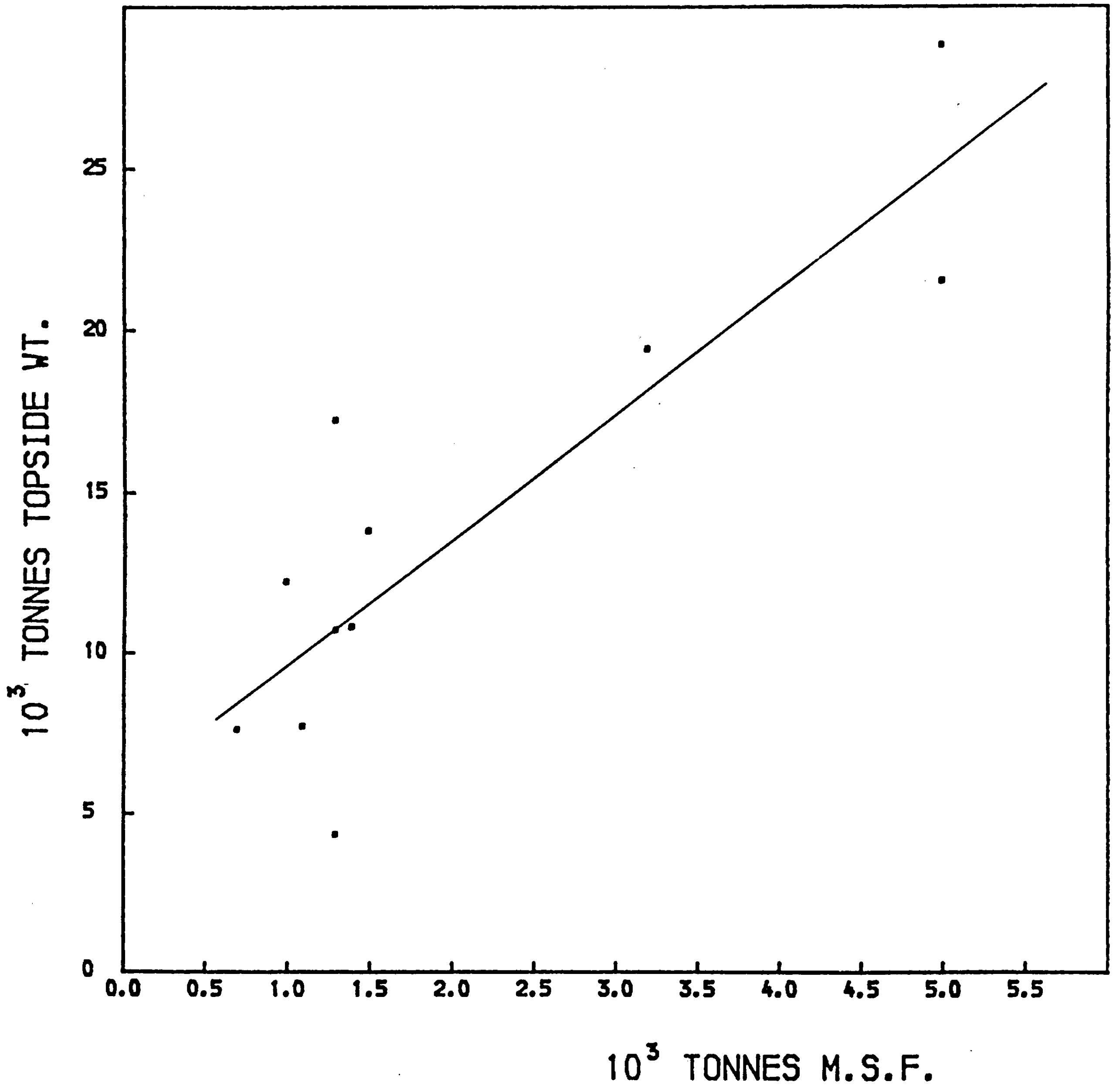


Fig.19 Topside Facilities Weight versus Module Support Frame Weight

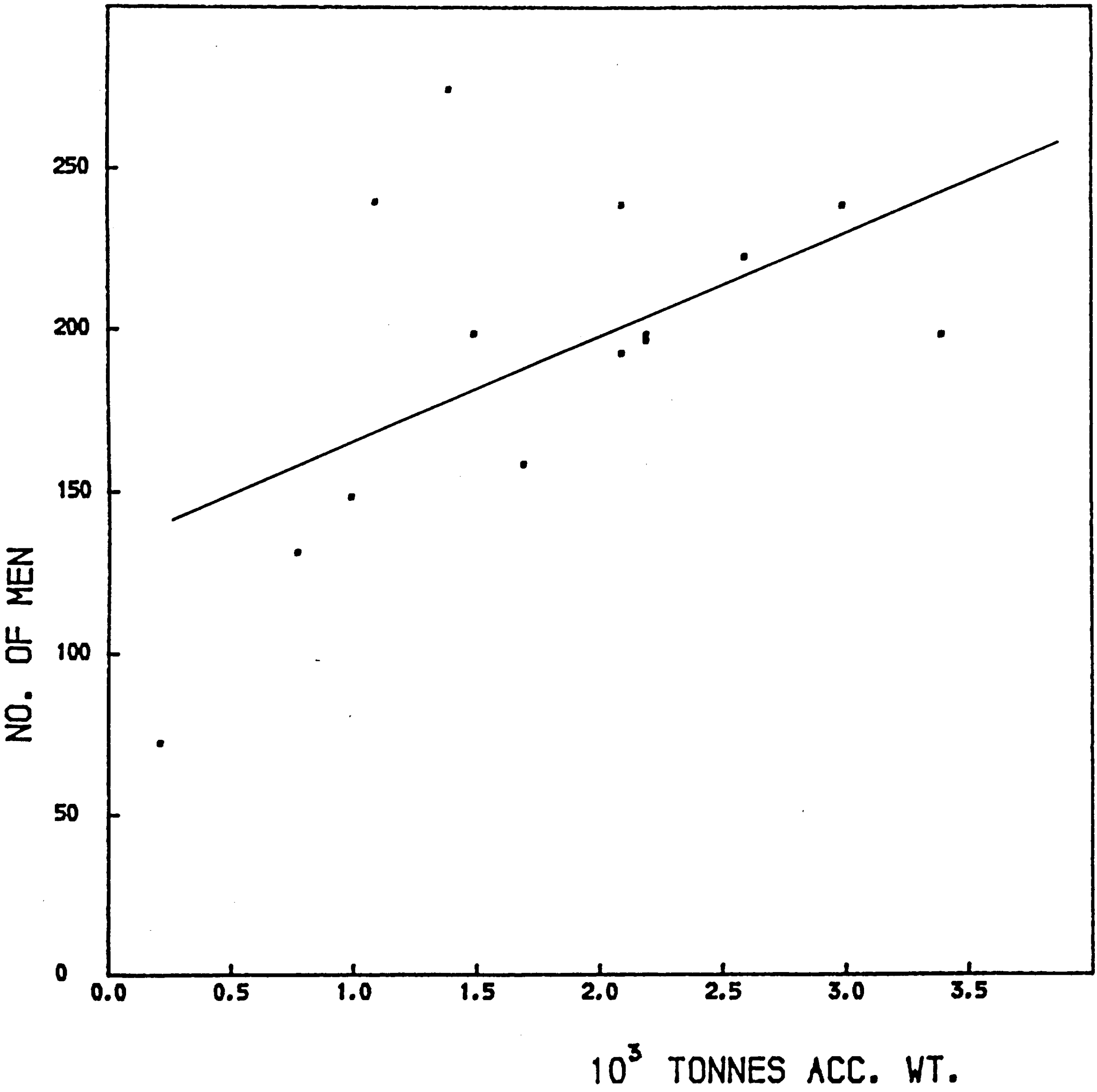


Fig.20 Number of Men versus Accommodation Weight

certain risk of overestimating the required area nevertheless it is reasonable to consider it as a safely factor rather than to have an underestimated deck area at the end of the design process. The type of deck structures are also given since this has major influence on the deck area.

Fig.(21) shows the relationship of the deck area and the production capacity. From this figure, it can be seen that most of the platforms in the North Sea have a deck area of between 1500 m and 3500 m even though there are a number of platforms having larger deck area.

4.5.3 Power Consumed

An offshore platform consumes large amount of power in order to drill, produce and process the oil and gas. Fig.(22) gives the result of an attempt to estimate the power consumed by steel jacket platforms. Again there are several platforms consuming an enormous amount of power compare to the number of barrels of oil being produced per day.

4.6 ASSESSMENT OF THE REQUIRED OPERATIONAL LOADING

An important early estimate in the design process is the mass of the topside equipment and modules, the deck structures, the flowlines and the jacket itself. Preliminary estimates can only be considered reasonable and in this study the need to keep the structural analysis simple must also be considered.

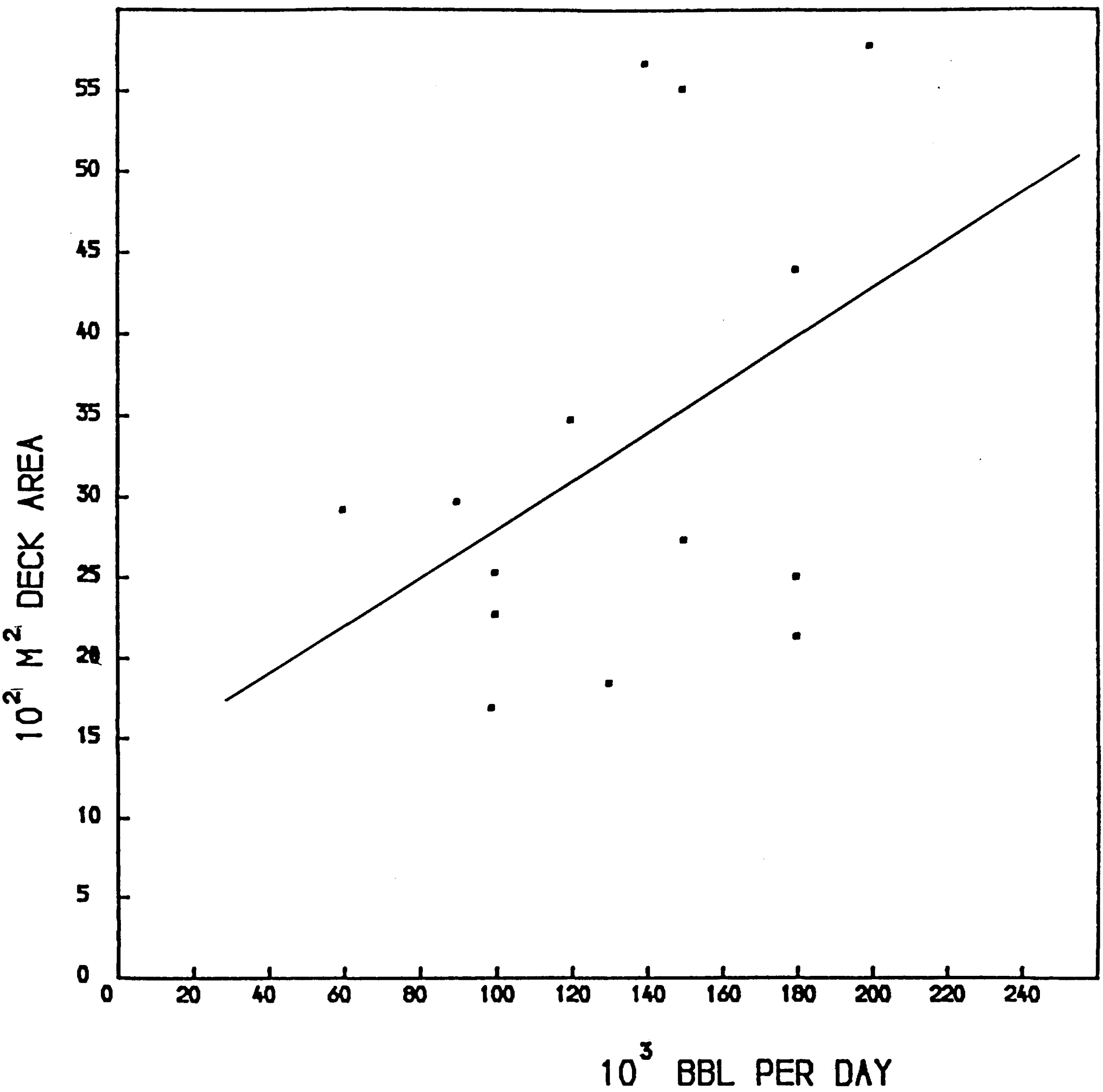


Fig.21 Deck Area As a Function of Oil Production Capacities

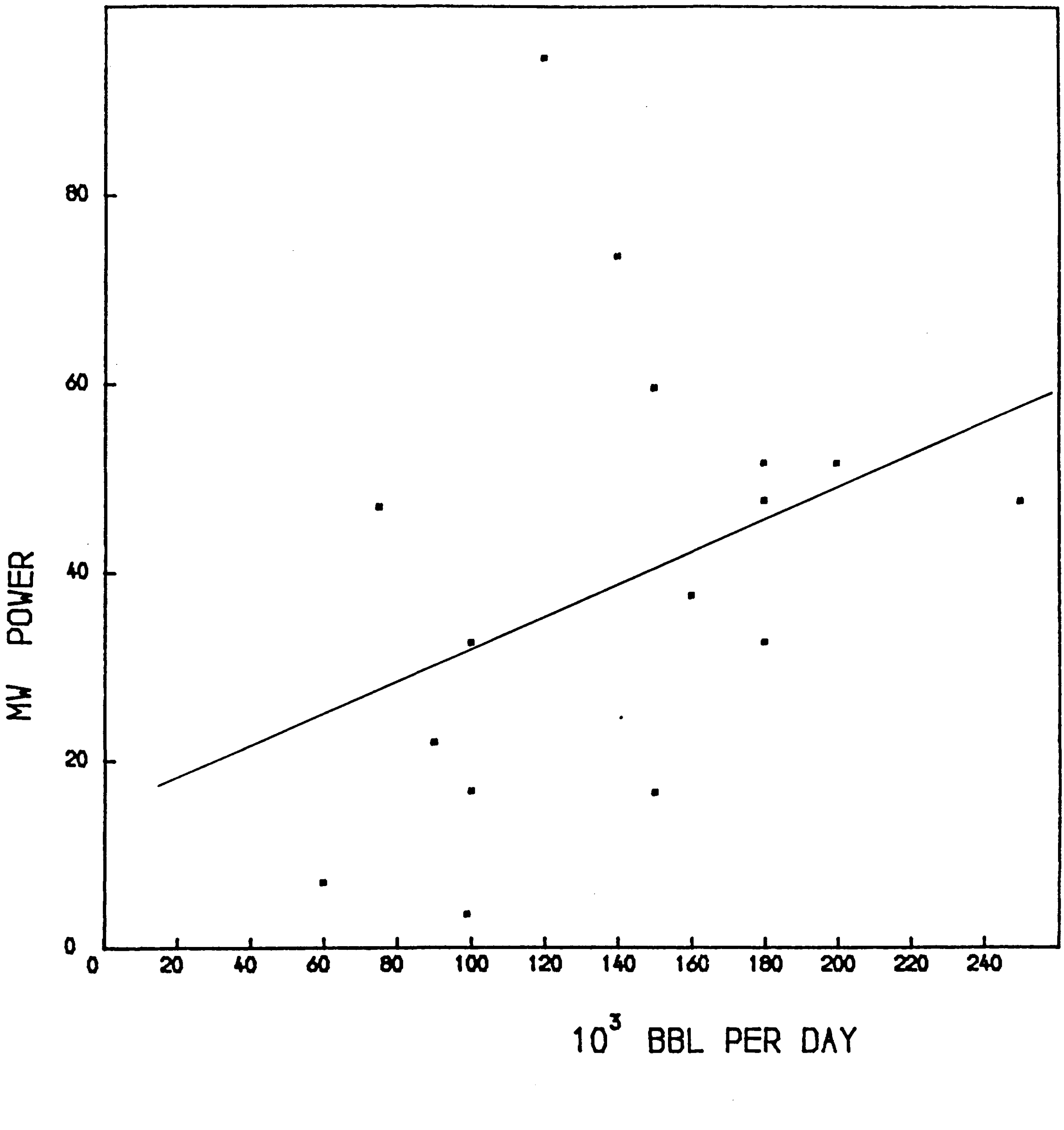


Fig.22 Power Consumed As A Function of Oil Production Capacities

4.6.1 Topside Mass

This includes equippment and module masses except the accommodation and the deck mass. Fig.(18) indicates that for North Sea platforms, oil production of 75000 barrels per day requires a topside mass between 5000 and 9500 tonnes.

4.6.2 Accommodation Modules Mass

A reasonable number of personnel in the South China Sea might be 150 and Fig.(20) indicates that the associated module mass would be 750 tonnes.

4.6.3 Frame and Flowline Mass

Fig.(19) indicates that for a topside mass of about 7500 tonnes, the jacket frame is about 600 tonnes. Flowlines would be an addition. The jacket frame and the flowlines masses should be incorporated in the frame analysis member by member. They are viewed as an equivalent addition to the topside mass for simplicity.

The total mass of the top of the jacket frame was taken to be 9000 tonnes equally divided among the legs. Approximately this could represent:

Topside	7500	tonnes
Accommodation	750	tonnes
Frame allowance	500	tonnes
Total	9000	tonnes

The North Sea and the South China Sea have similar depth of water. Since the expected wave height in the South China Sea is less than the North Sea, the frame mass could be less.

CHAPTER 5

ENVIRONMENTAL CRITERIA ANALYSIS

5.1 INTRODUCTION TO ENVIRONMENTAL LOADING

The contribution of the environmental criteria such as waves, currents and winds to the overall loading on an offshore platform are of major importance because of the large forces produced on the submerged as well as the upper exposed parts of the structure.

For the design of steel jacket platforms, environmental criteria are required for three main investigations: deck clearance analysis, static strength analysis and fatigue strength analysis.

Deck clearance analysis is to investigate whether there is a sufficient clearance between the water level and the deck structure of the platform. Static strength analysis is concerned with the strength of the members and joints of the jacket under maximum loading and is governed by the applied loading in extreme storm and operating conditions. Fatigue strength analysis is to ensure that the structure, in particular the welded tubular joints, have adequate strength to resist failures due to the passage of waves through the structure.

The realistic assessment of the environmental citeria is fundamental to sound structural design. The diverse environmental conditions offshore, difference in water depth, sea bed topography and the influence of nearby shores present a challenge to the meteorologist and oceanographer to predict criteria that meet requirements for both safety and economy.

To this end, the environmental loading conditions should be based on statistical data for waves, currents, winds and tides representative for the design life of the structure in question. Parameters of main concern are the distribution of the wave heights and the corresponding periods although special attention has to be given to the duration of storms, continuous evaluation of up to date storm spectra, breaking waves, impact loads and water movements such as currents and the direction of these loads.

The design environmental loads used for offshore structures are normally based on the environmental conditions over periods of 50 or 100 years, while the design life time is usually about 20 to 30 years.

The following section develop these considerations to obtain the environmental and operating criteria for the South China Sea, East of Malaysia.

5.2 WAVE ENVIRONMENT

When the wind blows over the sea, waves are generated. In any area the waves vary in height and length. At any location the height and length of the waves also vary with time. The height and length generated depends on the intensity of the wind, the distance it blows over the sea and the length of time it blows. A convenient way of qualifying a sea-state is by the significant wave height (H_s), defined as the average height of one-third highest waves over a period of time and the average period (T_z) of all waves.

The sequence of the calculation procedures needed to establish the structural loading due to waves generally involves some or all of the following steps:

1. Establishing the wave climate in the vicinity of the structure, either on the basis of recorded wave data, or by hindcasting from available oceanographic data.

2. Estimating design wave conditions for the structure.

3. Selecting and applying a wave theory to determine the corresponding fluid particle kinematics.

4. Using a wave force formulation to determine the hydrodynamic forces on the structure.

5. Calculating the structural response.

6. Calculating the structural loading, which includes base shear and moment, stresses and bending moments.

5.2.1 Method of Analysis

The development of rules and regulations to specify the nominal and extreme loading conditions, the translation of these conditions into hydrodynamic loadings, and the execution of the formal calculations of the structure constitute the essence of analysis and design are the stages of analysis. Majority of response calculations can often be dealt with by 'quasi-static' wave passage type calculations; but shorter waves (required for fatigue analysis) may need a dynamic analysis which allows for movement of structural members. This is necessary for fixed offshore structures in depths exceeding 100 m because such structures generally have natural frequencies falling in the range of the expected wave frequencies, which may lead to a dangerous condition of structural resonance. These may be performed through the use of two distinct methods:

5.2.1.1 Deterministic Analysis

This method of structural analysis has been far the most commonly used as regards to design of offshore structures. This method is valid for both static and dynamic analysis.

The wave loads, which are of major importance for the ordinary as well as the extraordinary loading conditions, are frequently represented as quasi-static loads serving as input for the static strength analysis. Thus, the hydrodynamic load has been taken from 'frozen' design wave considerations, using a monochromatic representative of the largest or unfavourable (but still realistic) wave likely to occur at the site within a suitable return period, usually the 1 in 50 years or 1 in 100 years wave.

This method is preferable for several reasons: direct approach in the design process, the nonlinear loads (drag and lift) can be included in the wave loading conditions, and applicable to nonlinear waves, including Stoke's 5^{th} order theory and the stream function theory.

The main difficulty in this method is to determine the wave period. To apply the maximum force with no regard to the period would lead to unrealistic results in many cases. Further investigation is necessary to clarify this problem, but until better knowledge of the subject is obtained, a 20 seconds limit derived from energy considerations seems appropriate [42].

This method of approach will be used throughout the present study.

5.2.1.2 Stochastic Analysis

As an alternative to the deterministic design wave method, stochastic analysis have frequently been used to evaluate loads on offshore structures. However, this method can only be justified if reliable transfer functions for the load responses can be established within reasonable accuracy limits. The implication is that nonlinear loads such as drag forces and others must be small in comparison with the linear loads such as the inertia forces.

By the reasons pointed out above, this method of analysis would normally be appropriate for gravity structures. If the spectral analysis method is applied by specifying only a few spectra, the same problem arises when trying to choose the peak period of the spectrum as one has in choosing the wave period in the design wave analysis. Consequently, careful consideration must also be given to the location of the wave spectrum along the frequency axis.

5.2.2 Prediction of the Extreme Wave Height and the Corresponding Period for South China Sea

The starting point for the estimation of a design wave in most cases is the scatter diagram which gives the probability of occurence of various sea states. The main sources for this kind of information has so far been the data collected from weather-ships, light vessels, and merchant ships. Reference (20) provides tabular wave data based about a million visual observations collected from ships in service worldwide over the 8 year period (1953 to 1961). In spite of the uncertainties associated with visual observations, it is still widely used because it offers global coverage and is still often the only source of data readily available to meet engineering requirements. However, we may soon expect very much more data from recent satellite measurements.

Having obtained the modified scatter diagram for South China Sea (Fig.23), values are summed by rows to find a histogram of significant wave heights and hence a percentage exceedance curve is plotted (Fig.24). For the fifty year value of the significant wave height, the data from the percentage exceedence curve are plotted on the Weibull Probability paper and adjusted by a constant selected to give the best least squares straight line through the points (Fig.25). The evaluation of the corresponding period is done by

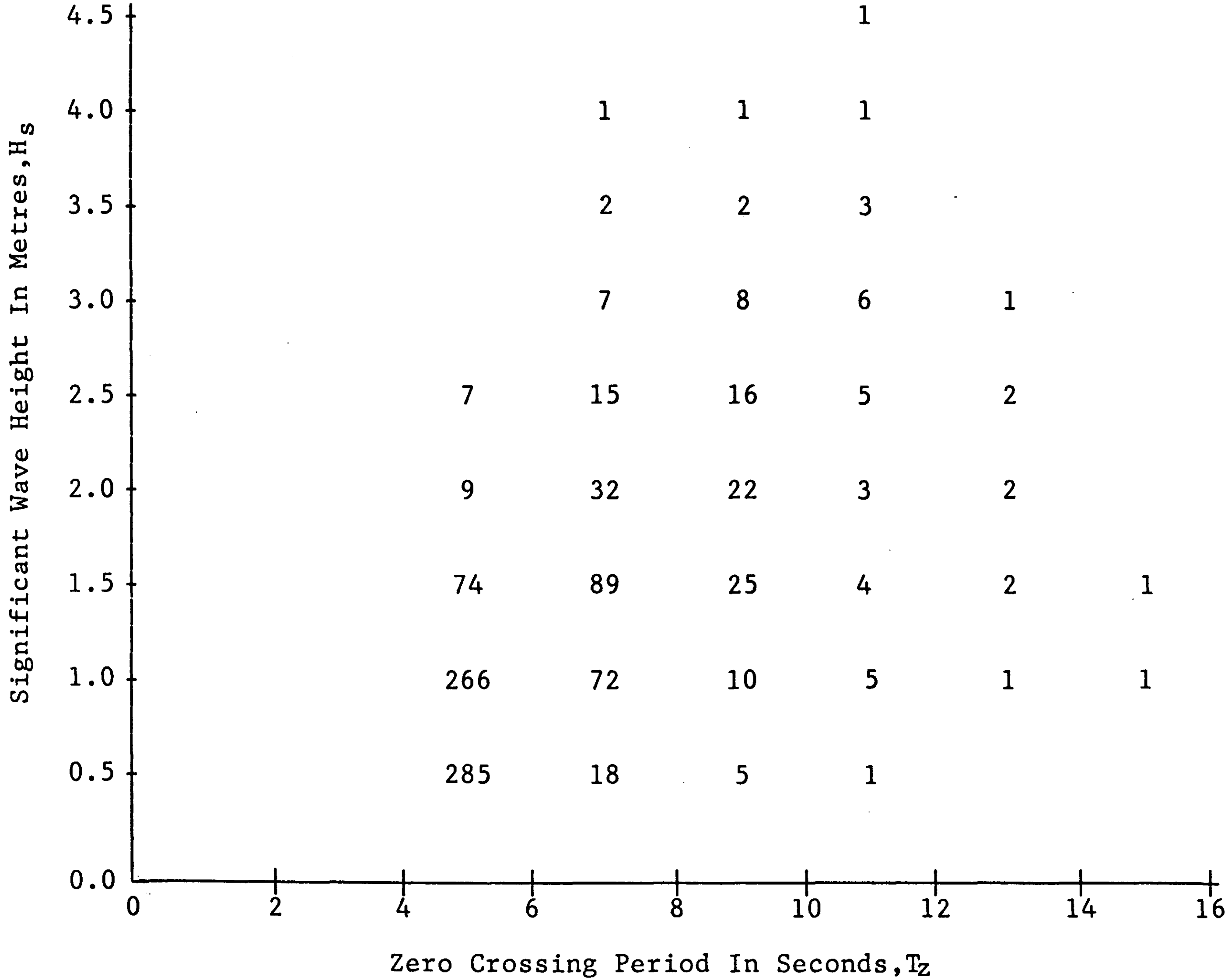


Fig.23 Scatter Diagram for South China Sea

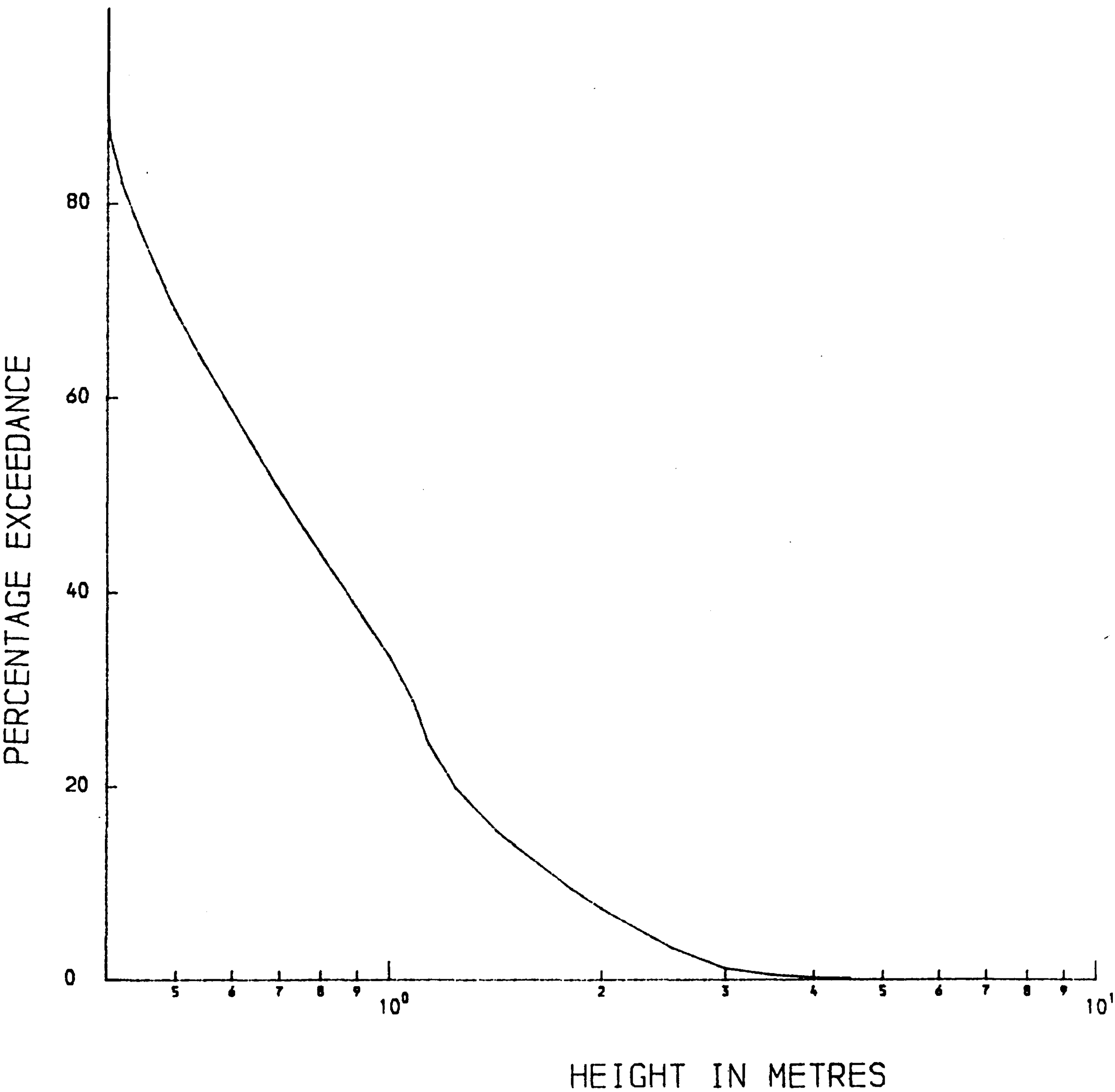


Fig.24 Percentage Exceedance Curve for South China Sea

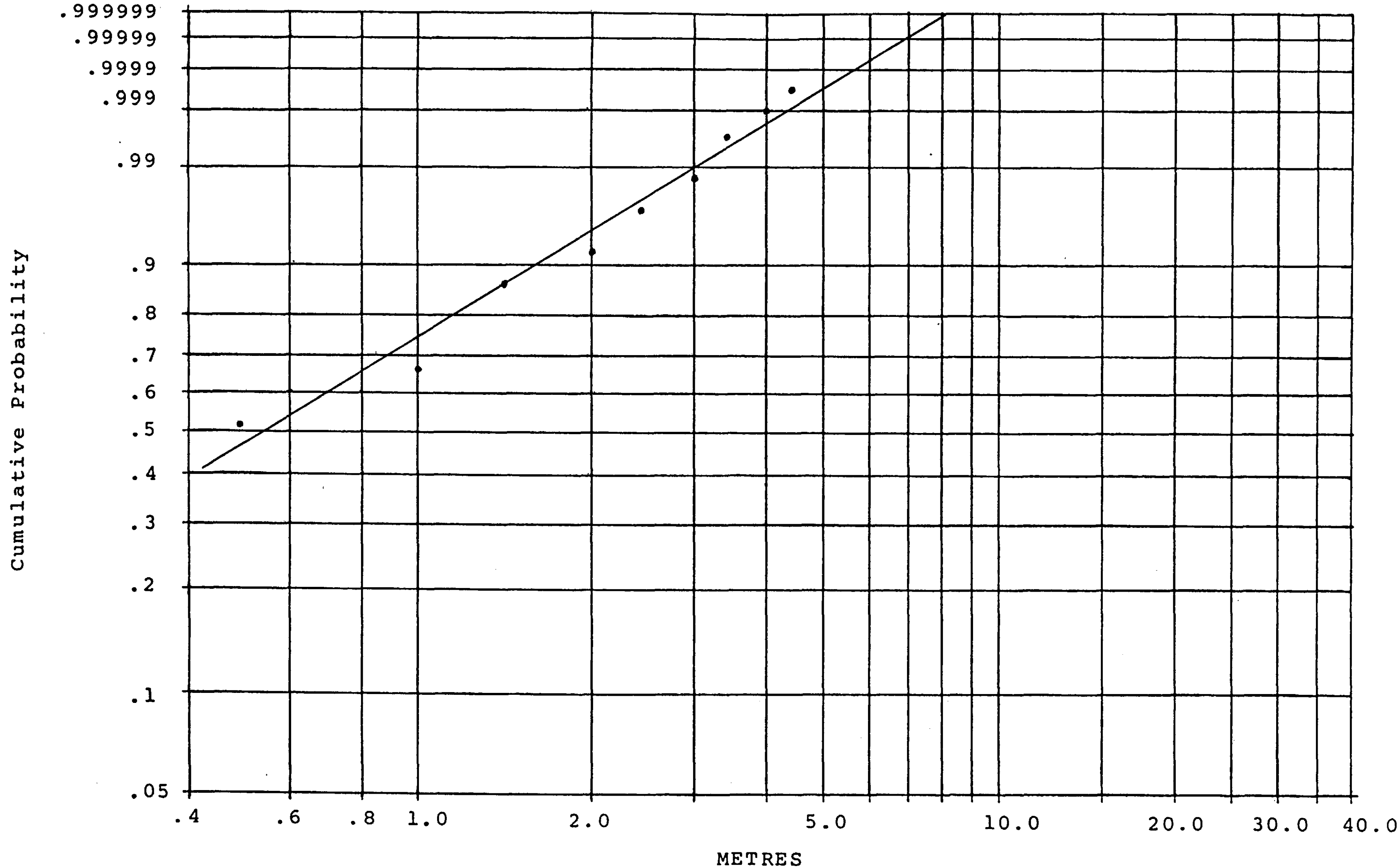


Fig.25 Cumulative Distribution Of H_S Weibull Scale for South China Sea

judgement from the scatter diagram.

5.2.2.1 Individual Wave Height Distribution

For deterministic fatigue calculations, the individual wave height distribution is required. This can be derived from the wave climate obtained from the scatter diagram. For each sea-state, the number of individual waves is calculated by dividing the duration of the sea-state by the average value T_Z. The Rayleigh distribution function is used to obtain the distribution of individual waves within a sea-state. The following equation is adopted [22]:

$$n = N/\exp(2(H/H_s)^2)$$

The total individual wave height is obtained by summing this procedure for all the sea-state in the wave climate. Fig.(26) shows the individual wave height distribution for South China Sea.

5.2.3 Review of the Relative Validities of Wave Theories

At present, there are at least twelve available wave theories which can be selected for the design wave representation [8]. One who is confronted with this choice, however, has only general guidelines pertaining to the relative depth conditions for which a particular theory was developed, and also an intuitive belief that the additional effort required to use the higher order wave theories

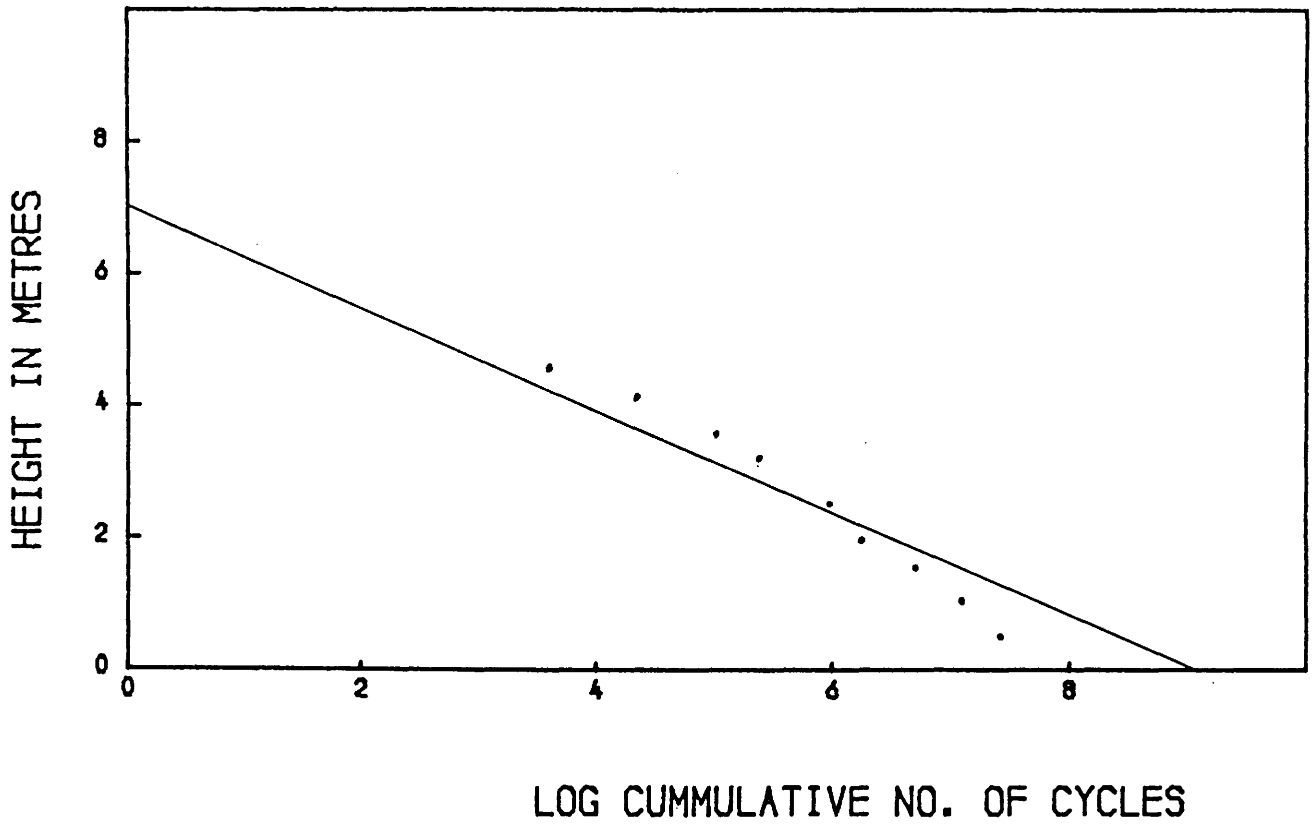


Fig.26 Individual Wave Height Distribution Curve for South China Sea

should be rewarded by more accurate results. Because most of the theories are difficult to apply, the differences in the particular design parameters predicted by several theories are not readily determined.

The Airy wave theory is useful for preliminary calculations involving assumed design waves even though the heights of such waves may exceed the restiction that they be should small in comparison with the wave length and water depth. The question naturally rises as to what range of values of the ratios of the wave height to wave length for which the simpler Airy theory can be used to obtain a reasonably accurate estimate of the wave characteristics. A main feature of the more accurate Stokes and Cnoidal theories is the increase in the amplitude of the crest of a wave over that given by Airy theory. This accordingly suggests a simple means for assessing the applicability of the Airy theory, namely that the theory can be considered applicable for waves whose crest amplitude differs from that determined from the more accurate theories by no more than some assigned percentage. In this way, a range of values of wave height to wave length can be established for which the Airy theory can be expected to give results of acceptable accuracy.

Fig.(27) shows such range for arbitrarily chosen allowable error in the crest amplitude of 10% . With a wave height of 7 m, water depth of 80 m, and wave length of 192 m, the application of the Airy theory seems to be best suited for analysis of the stucture in question.

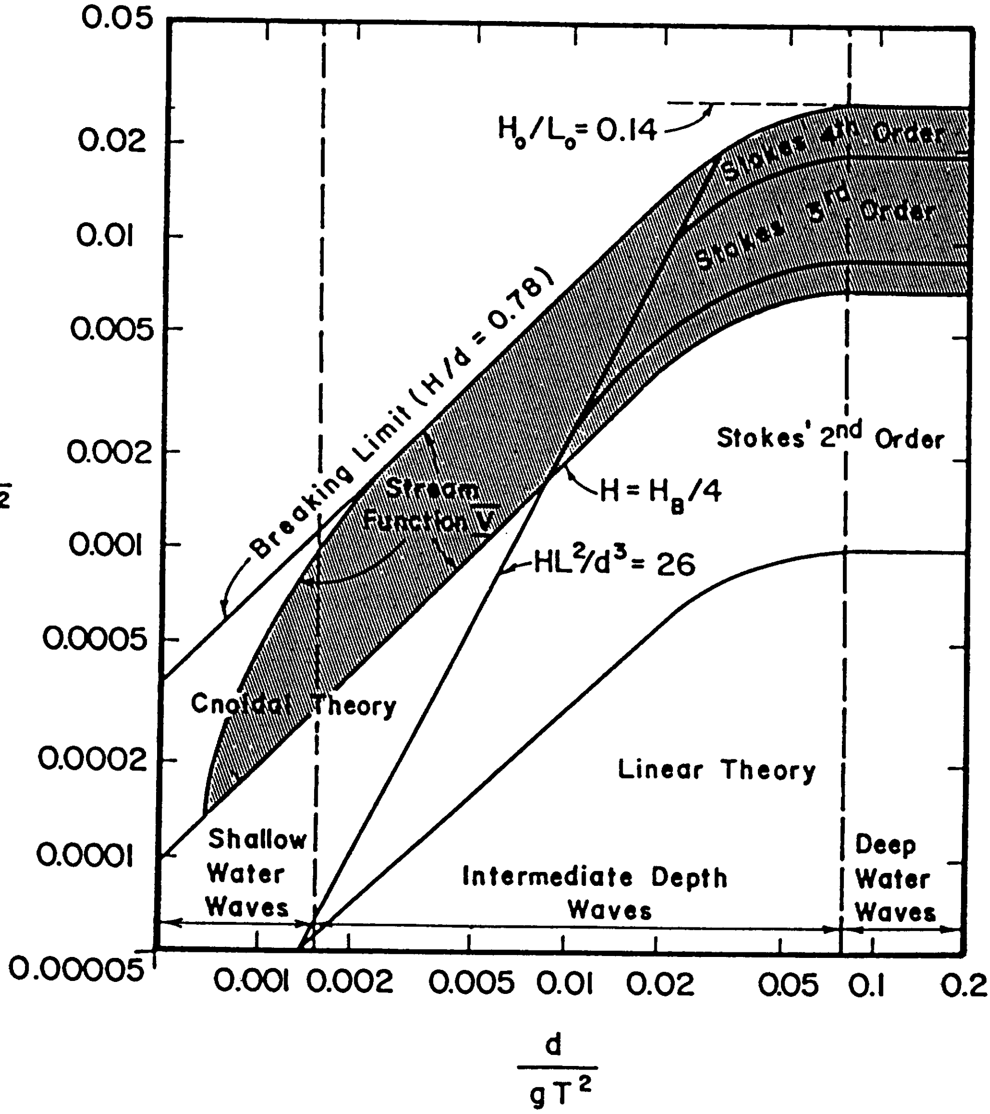


Fig.27 Ranges of Suitability for Various Wave Theories as Suggested by Le Mehaute (1976)

5.2.4 Wave Force Formulation

Hydrodynamic force formulation on offshore structures are complicated by many factors involved, such as the nonlinear relation between water particle kinematics and water surface displacement, the turbulent flow process about a structural member, the natural variability of wave forces and the possibility of resonance between waves and structures. Investigators in the past years have found it necessary to abandon any rigorous mathematical approach and take up something simpler to make any reasonable predictions of the forces on offshore structures.

The computation of wave force on a structure from the particle motion of the surrounding water was first considered by Morison et al (1950) with the restriction that the diameter of the structure is small in comparison with the length of the waves encountered, say one tenth or less so that the motion is unaffected by the presence of the structure itself.

This seems to be the most widely accepted approach to the calculation of the wave forces on a rigid body, based on the assumption that the wave force is expressed as the linear sum of a drag force, due to the velocity of the water flowing past the body, and an inertia force, due to the acceleration of the water. Morison states that the total force on an incremental length, ds, of a structural member is given by

$$dF = \frac{1}{2}C_D \rho U|U|ds + C_M A\rho \dot{U} ds \quad \longrightarrow \quad F = \int_0^{\eta} dF$$

This concept necessitates the introduction of a drag coefficient (C_D) and an inertia coefficient (C_M) in the expression for wave forces and assumes that the forces can be added ignoring the phase difference.

The relative importance of the drag or inertia forces in a particular case depend on the type and size of the structure and the nature of the wave conditions. Broadly it may said that the drag loads are the result of the flow separation induced by the relative velocity of fluid and are most significant. Inertia loads are more significant for structural components of large sectional dimensions.

The component normal to the drag force is known as lift force which is due to eddies forming altenately on each side aft of the structural member. Lift forces (dF) on an elemental length (ds) of piling can be defined in a form analogous to the drag force:

$$dF = C_L \rho D \frac{U^2}{2} ds$$

Diffraction forces represent another regime of hydrodynamic forces primarily connected with large volume structures. Diffraction forces are due to the scattering of incident waves by structures which become significant when the structural member dimensions are a substantial fraction of the wave length. Force models for describing the wave diffraction theory have been developed by MacCamy and Fuchs

(1954) and others, generally by the use of potential theory and the method of finite differences or finite elements.

Extensive effort has been made in the past in obtaining prototype and laboratory values of the force coefficient connected with the Morison equation. Numerous studies have been reported in attempting to relate the coefficient to dimensionless numbers such as Reynolds number and Keulegan-Carpenter number, and results often shown considerable scatter.

Shown in Table (15) is a list of representative research results on the values of C_M and C_D. The large discrepancies among studies are attributed to factors such as the irregularity of the ocean waves, different wave theories used, free-surface effects, marine growth roughness, and omission of some other important parameters which have not been incorporated into the analysis such as the effect of ocean currents on separation, vortex formation and frequencies dependencies.

Laboratory research by Sarpkaya (1976) and Garrison (1976) in attempting to correlate C_M and C_D with N_{KC} and N_{Re} produced a very promising approach in analysing test data in a systematic manner. Their analysis showed that at the higher values of N_{Re} ($N_{Re} > 10$), C_D approaches 0.65 and C_M approaches 1.6. The coefficients C_D and C_M were also found to depend on both N_{Re} and a frequency parameter ($=D^2/\nu T$) when the coefficients were plotted against N_{KC}. There is very little scatter and the confidence level is quite good.

Table 15 : Wave Force Coefficients For a Cylindrical Members as Pertaining to Application of Morison's Equation Based on Different Wave Theories [7]

Wave Theory	Force Coefficient C_D	Force Coefficient C_M	Remarks	Reference
Linear Theory	1.0	0.95	Mean values from ocean wave data on 13 and 24 in. diameter cylinders	Wiegel, et al (1957)
	1.0-1.4	2.0	Recommended design values based on a statistical analysis on published data with a 98% confidence level	Agerschou and Edens (1965)
Linear Filtering	0.6	1.5	Mean values from Wave Force II data based on highest 50% of measured peak forces	Wheeler (1969)
Stokes Third Order	1.34	1.46	Mean values from laboratory oscillatory flow on 2 to 3 in. diam. cyl.	Keulegan and Carpenter (1958)
Stokes Fifth Order	0.57	3.1	Mean values from a statistical analysis of Wiegel, et al's data	Bretschneider (1967)
	0.5	1.2	Mean values from Wave Force I data. Small waves at 30 ft water depth	Evans (1969 Marshall and Bea (1976)
	0.58	1.76	Mean values from Wave Force II data. Larger waves at 100 ft water depth	
	0.8-1.0	2.0	Recommended design values based on a statistical analysis of published data with a 98% confidence level	Agerschou and Edens (1965)
Cnoidal	Same as Stokes 5th		For small amplitude waves	Mallery, et al (1972)
	Lower than Stokes 5th		For steep waves near breaking	
Stream Function	0.55	1.33	Based on analysis of Wave Force I and II data for high Reynold's number range	Aagaard and Dean (1969)

Lift forces are related to the eddy shedding frequency by the so-called Strouhal number S (S = fD/U). For a circular cylinder, the eddy shedding frequency corresponds to S = 0.2 at the subcritical Reynold number. Lift forces become significant when there is a correspondence between the wave frequency and the eddy shedding frequency, producing a resonance phenomenon with natural frequencies of structural response. The lift coefficient (C_L) for smooth cylinders depends on N_{KC} and N_{Re} for intermediate values of N_{KC} and N_{Re} as reported by Sarpkaya (1976). For relatively large values of N_{KC} and N_{Re}, the lift coefficient approaches a value of 0.25.

The method of estimating the wave loading and the validity of the Morison equation has been covered widely by numerous references (Ref. 5-8). However, it is important to outline a number of prime factors that must be considered before the results of the equation can be used for structural analysis of any offshore structures.

Morison's equation was developed for a single vertical cylindrical pile infinitely long, and with a diameter which is small compared to the wave height, wave length and water depth. Special considerations and modifications have to be made on the applications of this equation to the not-so-ideal situations where a structural member may be inclined, fouled by marine growth, affected by flow conditions from adjacent members and/or complicated by surface wave slamming effects and other unaccounted factors.

5.2.4.1 Inclined Members

A limited amount of material has been published on the application of the Morison equation to inclined mebers such as cross bracings of a fixed offshore platform. However, approaches to the problem have been proposed by Chakrabarti, et al (1975) and others, all of which are within approaches generally used by industry. The assumptions involved in these approaches are either one of the following:

1. The drag and inertia force resultants acting on a projected area of the inclined cylinder need to be considered.

2. Only the components of pressure acting normal to an inclined member produce loads.

3. Only the components of velocities and accelerations normal to the inclined member produce loads.

5.2.4.2 Interference and Shedding

The forces on a member in close proximity to another will be affected by the wake field. It is possible for the vortices in the wake from the first member to excite the dynamic response of the member behind it, leading to an effective increase in forces computed from Morison's equation. Conversely, it is possible that a member surrounded on all sides by larger members will be sheided and experienced a smaller force. In most cases only the drag component of the wave induced force will be changed.

5.2.4.3 Added Mass of a Group of Members in Close Proximity

The effect is the inertia counterpart of the interference or sheiding effect on the drag force. If several members are placed close together, for instance, conductor tubes in an offshore oil production platform, there will be a tendency for a proportion of the mass of water enclosed by them to act as part of the structure. This will lead to an effective increase in the inertia coefficient C_M for all the members.

5.2.4.4 Splash Zone

A rather important problem for which the Morison's equation is not adequate arises in the so-called splash zone of offshore structures where large forces are generated on platforms in the vicinity of the free surface, due both to the high particle velocities and accelerations and the concentration of exposed areas (boat landings, barge bumpers, legs and braces). In this zone, designers have often neglected the effect of wave slamming, cyclic bouyancy, lift forces and wave force components which may be of significant magnitude to be of concern, several splash zone failures in the North Sea have actually happened.

5.3 CURRENT AND ITS EFFECT

When a wave encounters a current, its length and amplitude undergo some changes, that is, when the current is in the direction of the wave propagation, the wave amplitude decreases and the wave length increases, in opposing current, the situation is reversed. The analysis of the interaction of waves with pre-existing and/or wind drifts and tidal currents and the interaction of the modified wave-current combination with rigid or elastic structures and their components require different mathematical approaches, relevant observations, and experiments that are applicable to all or some of the circumstances.

The wave-current combination may be treated as a complex fluid-mechanic phenomenon where the interaction of waves and current is taken into consideration or as a relatively simple one where the interaction is ignored. Thus, for design waves representative of extreme storm conditions, the contribution of the current force is usually small enough to allow neglect of current effects.

5.4 STILL WATER LEVEL

Data for still water level is required in order to determine the deck clearance and the internal loading in the jacket platform. The still water depth varies due to tidal effect and changes in the atmospheric conditions (surges). The former is cause by the gravitational attractions of the sun and moon, while changes in atmospheric conditions occur in cyclonic depressions, where the local atmospheric pressure causes the level of the sea to rise.

Tidal levels and extreme surges are normally predicted by hindcasting of historic storms in conjuction with mathematical models similar to those used in predicting currents.

5.5 WIND ENVIRONMENT

Wind loading represents virtually all the environmental loading on the platform superstructure and in storm conditions can account for up to 20% of the total horizontal environmental loading on the platform as a whole. In addition to this horizontal loads, the overturning effects produced on the module structures introduce vertical loadings on the module support frame which produce diffential deflections of the module seating points. These diffential deflections in turn cause the module reaction to redistribute over the module support frame. This can be a significant effect for the modules which support tall towers or long flare booms.

Basic data of mean wind speeds and the frequency of their occurence are necessary in order to make the loading calculations viable. As wind speed varies with height above the sea surface, wind data are normally corrected to a reference height of 10 m above sea level. The designer requires wind criteria for different mean wind speeds, for example, the local structure might response to the 3-second gust, and the total structure to the one-minute mean.

Once the wind velocities have been determined, the estimation of the wind loads to be expected on the structures can be done. Interaction effects caused by the wind have to be considered because of the complicated geometry of the various components and the obvious space restriction. For example, the positioning of living quarters may make the use of the helicopter landing pad impossible in certain wind conditions, so care must be taken in choosing the relative positions of the components on the deck. For this reason a wind tunnel test on a model is most essential for detailed examination of this problem.

Unfortunately, no available data as prescribed above is obtainable for the South China Sea. It is then largely a matter of judgement as to how the maximum wind speed (available from Ref.(22) is used to calculate the overall wind forces. Table (16) summaries the environmental and operational criteria needed for the design of the offshore jacket platform for Malaysian waters.

Table 16 : Typical Environmental and Operational Criteria for a Production Platform in the South China Sea, East of Malaysia

Still Water level	:	70 m
Extreme Wave Height	:	7 m
Wave Period	:	11 s
Current Speed	:	0.36 m/s
Wind Speed	:	18 m/s
Tide	:	10 m
Marine Growth	:	10 to 30 mm
Temperature	:	82.6° F
Oil Production Rate	:	75000 bbl per day
No. of Conductors	:	10
Topside Weight	:	9000 tonnes
Number of Personnel	:	150

CHAPTER 6

STRUCTURAL ANALYSIS

6.1 PRELIMINARY REQUIREMENTS

As mentioned in Chapter 3, one of the criteria to be considered before the configuration for the steel jacket platform can be chosen is the deck clearance needed for the platform. If an extreme wave, higher than the design wave was to overrun the platform deck, excessive loading would be applied to the jacket structure. The purpose of the deck clearance should be such that the probability of occurrence of the water level that overruns the deck is the same as the probability of failure of the jacket structure.

In lieu of precise calculations, the clearance is based on the extreme water level with return period, perhaps the fifty years, specified for design plus a safety allowance to cater for waves greater than the design waves. An arbitrary envelope condition is normally specified in terms of tide, surge, wave height and the safety allowance.

A combination commonly used is that the maximum water level should be taken as the mean high water spring tides plus storm surge and wave crest consistent with the design return period plus a safety margin of 1.5 metres.

6.2 DESCRIPTION OF THE STRUCTURE

The jacket platform geometry was a tower framework, square in plan view, with vertical sides having a minimum amount of bracing largely to simpify the analysis. Fig.(28) indicates the structure. Although the framework does not meet the guidelines of [53], the existing bracings keep the deflections acceptable and the additional bracings to meet the guidelines can be incorporated.

The framework is composed of members with circular cross-section and the diameter and thickness of the members were the subject of some initial iterations to ensure that those finally selected would be satisfactory.

The base and the top of the structure has a dimension of 55 x 55 m and height of 85 m. Other main particulars of the structure are shown in the figure. A three dimensional representation of the tower structure with its member numbering is shown in Fig.(29).

6.3 STATIC ANALYSIS

Generally, two main conditions are analysed: one representing extreme environmental conditions with the return period specified for design and the other representing the normal day operating conditions. Only one platform weight distributions is considered and for the extreme conditions, the allowable stresses are increased.

In extreme environmental conditions, the loading on the platform is based on the simultaneous occurrence of a single extreme wave, the water level between the mean low-water spring tides and the mean high-water tides, and the design wind speed.

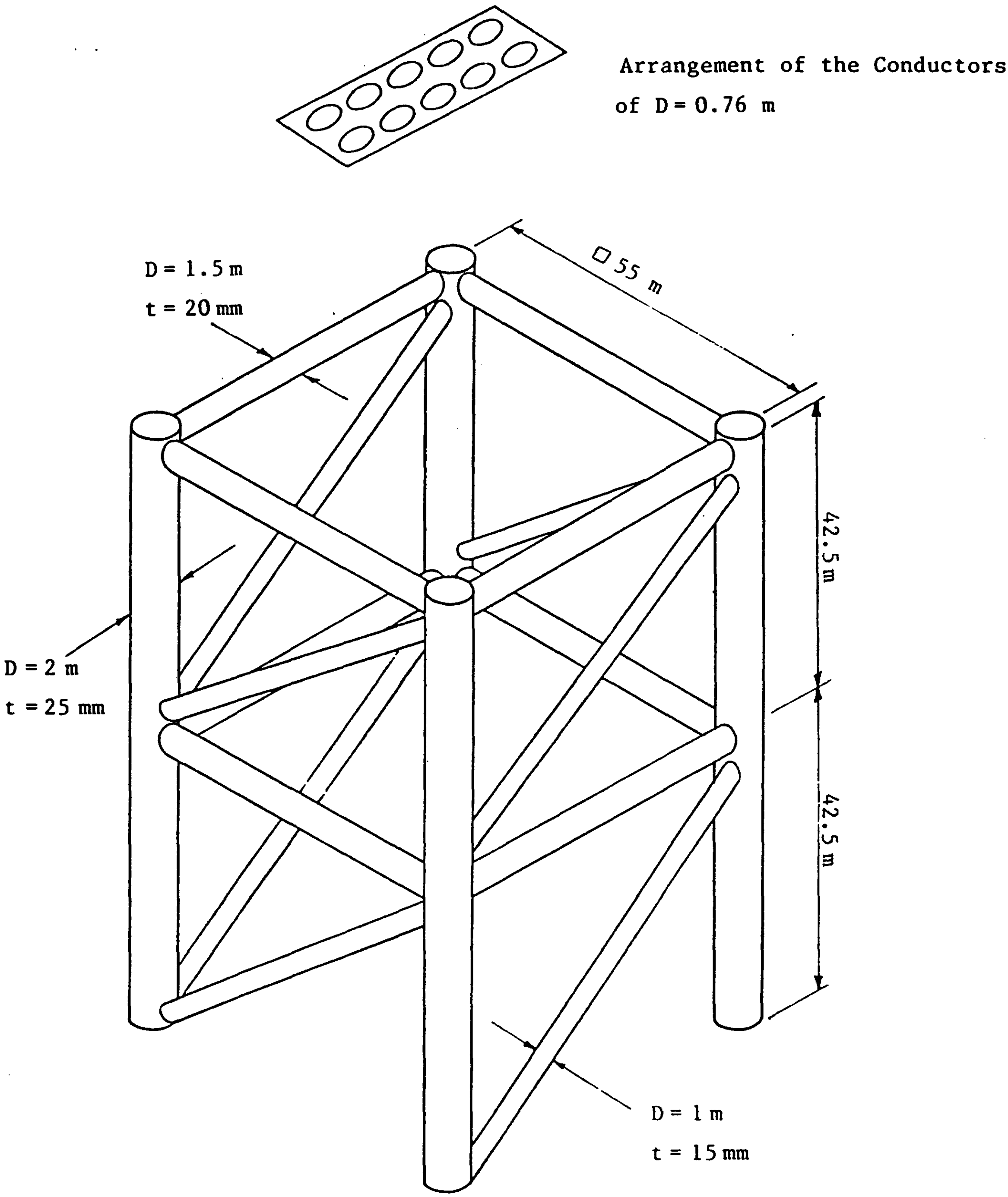


Fig.28 Main Particulars of the Jacket Structure

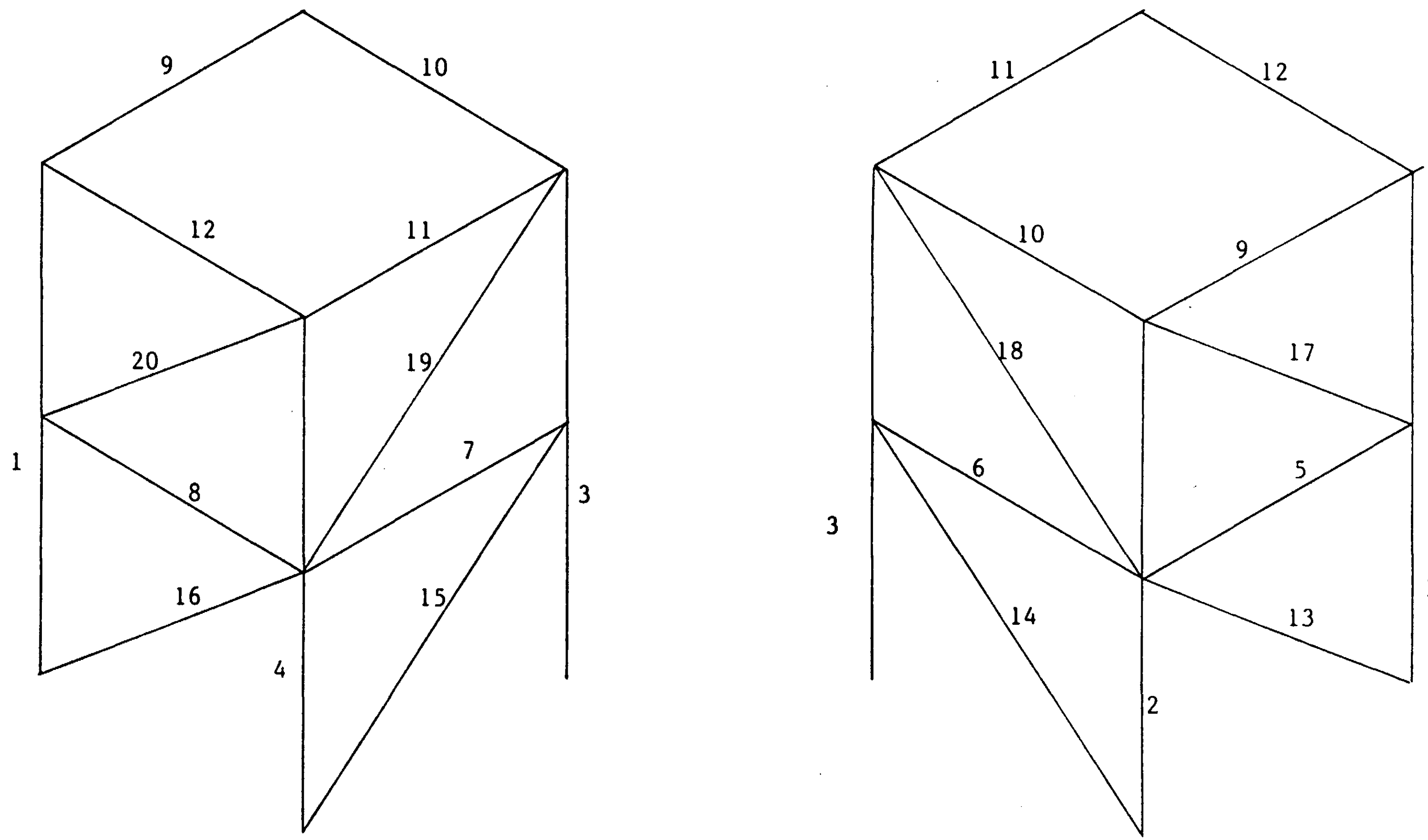


Fig.29 3-Dimensional Representation of the Jacket Structure

In the operating condition, the most severe environmental conditions during which day-to-day work operations will be allowed to continue is chosen.

6.3.1 Hydrodynamic Calculations

A large computer program, WAVLOA, written by INCECIK [2], is used in the hydrodynamic analysis of the structure. The main assumptions used in this program are:

1. Airy wave theory is adopted.

2. Sectional dimensions of members are small compared to the wave length.

3. Hydrodynamic damping is linear.

4. Hydrodynamic interference between members is ignored.

This three-dimensional program determines the wave loading in terms of nodal loads distributed throughout the structure. This format of output provides a ready means of input for the structural response analysis (Appendix C).

Since this structure is of a tower type, three values of the incident angle of wave were considered, namely 0°, 30° and 45°. Table (17) shows the results obtained in the extreme weather condition with different angle of incidence of the waves and Table (18) is the results for the operating condition. Hydrodynamic forces and moments on one of the conductors are given in Table (19).

Table 17 : Hydrodynamic Results of the Whole Structure (without conductors for the Extreme Weather Conditions

Wave Height = 7.0 m

Wave Period = 11 sec.

Item	Orientation of Waves	0°	30°	45°
Max. Forces (kN)	Surge	811.495	732.787	609.583
	Heave	363.401	357.792	357.889
	Sway	53.021	445.391	624.080
Max. Moment (kN.M)	Roll	3104.083	20504.963	28745.873
	Yaw	2145.251	4327.779	3262.140
	Pitch	36357.418	33386.781	27955.414

Table 18 : Hydrodynamic Results of the Whole Structure (without conductors) for the Operating Weather Conditions

Wave Height = 1.0m

Wave Period = 5 sec.

Item	Orientation of waves	0°	30°	45°
Max. Forces (kN)	Surge	52.948	52.627	102.745
	Heave	13.849	8.794	10.793
	Sway	3.538	38.358	103.035
Max. Moment (kN.M)	Roll	332.215	3043.601	7980.276
	Yaw	428.489	3102.276	159.965
	Pitch	3686.558	4264.423	7959.912

Table 19 : Hydrodynamic Results for One of the Conductors for the Extreme Weather Conditions

Wave Height = 7 m

Wave Period = 11 sec.

Item	Orientation of Waves	0°	30°	45°
Max. Forces (kN)	Surge	44.662	38.008	30.477
	Heave	0.000	0.000	0.000
	Sway	0.000	21.149	30.477
Max. Moment (kN.M)	Roll	0.000	1186.180	1720.313
	Yaw	0.000	0.000	0.000
	Pitch	2549.634	2158.088	1720.313

6.3.2 Frame Analysis of the Structure

Once the hydrodynamic loadings, due to the specified environmental conditions, on the proposed structure is determined, it is then combined with the operational loads to establish the maximum total loadings on the structure. Assuming that the dynamic effects are negligible, these loadings may then be used with structural methods to find the maximum stresses existing in each of the various members. If the members are adequately sized, these stresses will be within acceptable levels to prevent failure.

In performing this stress analysis, it is freqently sufficient to consider only the two cases where the direction of wave motion is along each of the principal horizontal axes of the structure and limit the attention to a two-dimensional frame analysis, as indicated in Fig.(30). Out-of-plane members in each case can be analysed by considering the resultant distribution force on them. Of course, when the geometry requires it, or when more accurate results are desired, a full three-dimensional structural analysis may be employed, with various wave directions assumed.

6.3.2.1 Program RJPFA [29]

A large computer program, RJPFA, is used to calculate the deflection and the member forces for the whole structure. This program uses the stiffness method of anlysis and is applicable for rigid joint plane frames (two-dimensional analysis).

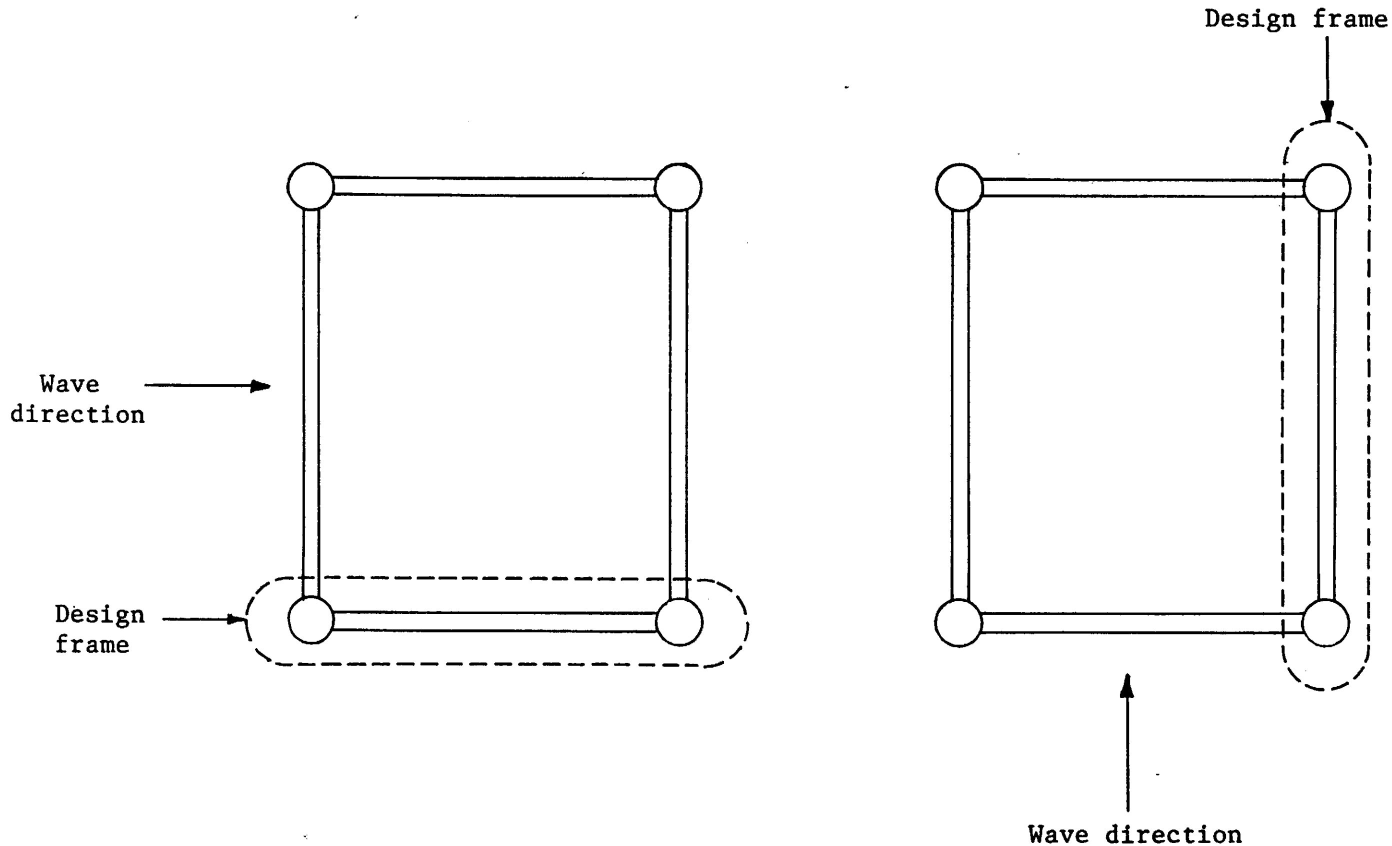


Fig.30 Design Frame for Two-Dimensional Structural Analysis

The input data required to run this program are:

1. Basic structural data including the number of joints, members, joint restraints, joint and intermediate forces.

2. Coordinates of all the joints.

3. Members position relative to the joints and their physical properties including E, A, I .

4. Specifying the supports of the framework in terms of joint restraints.

5. Specifying the joint forces; direction and magnitude.

6. Specifying the intermediate forces:
   a. the member on which it acts,
   b. the direction in which it acts,
   c. the type of force; concentrated or uniformly distributed,
   d. the magnitude,
   e. in case of concentrated force, its position from the end of the member attached to the joint with the lower number expressed as a proportion of the length of the member.

The output of this program includes:

1. Deflections of members
2. Member forces
3. Global forces and reactions.

The structure numbering is reorganised in order to cater for the different uniformly distributed loads obtained from the hydrodynamic calculations. Since all four faces of the structure are identical, only one side of the structure will be analysed as indicated in Fig.(31).

The stress analysis generally requires that some consideration be given to the interaction of the structure with the support piles. This is especially important for soft-soil conditions, where large deflections of the piles and the connected structural elements can occur at the ground-line. In this work the bottom of the structure is assumed to be restrained from any linear movement. The deck loading is taken to act as a point load on top of the structure as shown in Fig.(32).

Only the results of the 0° wave orientation analysed in this study since at this angle of incidence, the wave produced the maximum surge force and pitch moment which are greater than that of the 30° and 45°.

For each member of the structure, the distribution of the axial force (F_y), shearing force (F_x) and bending moment (C_z) along the length of the member is used as input data for the stress analysis by program MAX. STRESS.

6.3.2.2 Program MAX.STRESS

This program is used to calculate the maximum principal stresses and the shear stress for each member of the structure. The program

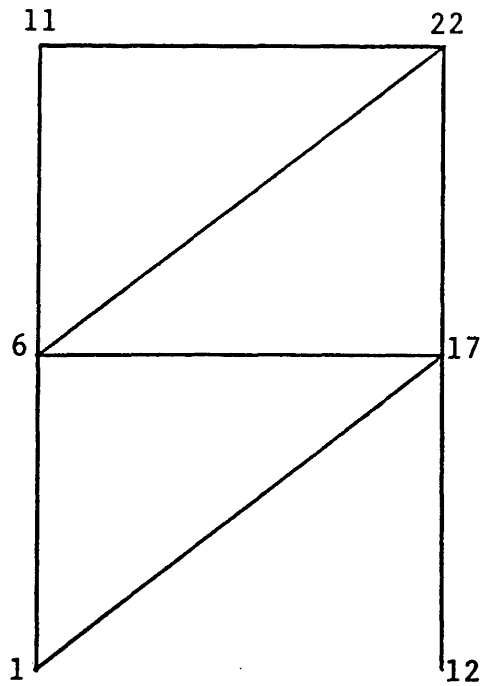


Fig.31 Joints Number of the Jacket Structure

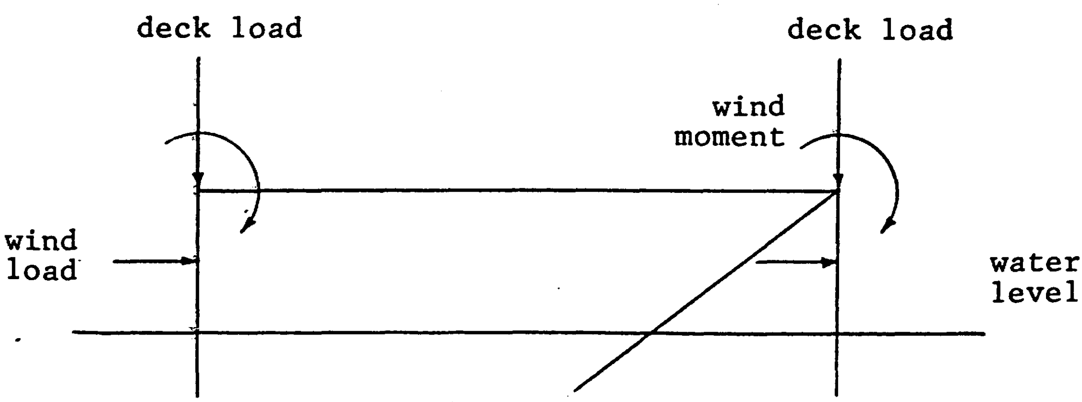


Fig.32 Deck and Wind Loading on the Jacket Structure

starts by picking up the physical properties of the member such as outside diameter and wall thickness, distance between member to the surface of the water, the forces (F_y and F_x) and the moment (C_z) and calculates the maximum principal stresses and shear stress by the method given in Appendix (E). Output of this program is given in Table (20).

6.3.3 Effect of Bending Stress Amplification

When members of an offshore structure are subjected to both bending and axial stresses, as is usually the case, the bending stress determined from the MAX.STRESS program may subject to some error because of the interaction with axial stress. This is further illustrated in Fig.(33), where it can be seen that the internal moment at any section of the member will depend on the axial loading and the deflection of the member.

With axial tensile stress, the effect is to reduce the bending stress from the value given in Table (20), whereas with axial compressive stress, the effect is to increase it. The decrease in bending stress resulting from axial tensile stress may be neglected, but the increase resulting from axial compressive stress clearly needs to be considered. This increased may be estimated using the amplification factor $\alpha \geqq 1$ defined by

$$\alpha = \frac{C_m}{1 + \sigma_a / \sigma_e}$$

Table 20 : Member Stresses

MEMBER	MAX. STRESS (kN/mm^2)	SHEAR STRESS (kN/mm^2)
1	0.1432	0.0716
2	0.1426	0.0713
3	0.1435	0.0717
4	0.1432	0.0716
5	0.1428	0.0714
6	0.1485	0.0742
7	0.1438	0.0719
8	0.1442	0.0721
9	0.1436	0.0718
10	0.1470	0.0735
11	0.1512	0.0756
12	0.1447	0.0723
13	0.1455	0.0727
14	0.1454	0.0727
15	0.1454	0.0727
16	0.1486	0.0743
17	0.1594	0.0797
18	0.1478	0.0739
19	0.1505	0.0752
20	0.1575	0.0787
21	0.1572	0.0776
22	0.1545	0.0772
23	-0.0109	0.0104
24	-0.0109	0.0101
25	0.0106	0.0100
26	0.0103	0.0099
27	-0.0118	0.0099
28	0.0086	0.0043
29	0.0014	0.0009
30	0.0040	0.0021
31	0.0066	0.0034
32	0.0066	0.0033
33	0.0092	0.0065
34	0.0113	0.0072
35	0.0203	0.0109
36	0.0211	0.0112
37	0.0112	0.0067
38	0.0125	0.0072

where C_m is a coefficient dependent on the loading and ranging from about 0.4 to 1.0.

The value of C_m equal to unity may always be chosen in the above equation for a conservative estimate. The evaluation of the buckling stress for members attached with rigid joints is more difficult. The general buckling stress formula is

$$\sigma_e = \frac{\pi^2 E}{(kL/r)^2}$$

where k is the effective length factor dependent on the end conditions of the member. Typical values of k for various end conditions are shown in Fig.(34).

In the structure being considered, the value k=2 is used to analyse the effect of the bending stress. We then have for this case;

$$E = 210 \times 10^9 \ \text{N/m}^2$$

$$r = \sqrt{0.0756/0.155} \quad \text{, thus}$$

$$\sigma_e = 2.53 \times 10^9 \ \text{N/m}^2$$

Since $\sigma_e > \sigma_y$ inelastic buckling analysis is required. Thus the equation below is used [34]:

$$\sigma_{cr} = [1 - \frac{1}{2}(\frac{KL}{Sr})^2]\,\sigma_y \qquad \text{where} \quad S = \pi\sqrt{(\frac{E}{\sigma_y/2})}$$

$$\sigma_y = 234\ \text{N/mm}^2$$

$$\sigma_p = 0.5\sigma_y$$

$$S = 66.4 \qquad \text{thus,}$$

$$\sigma_e = 219\ \text{N/mm}^2$$

Taking member 17,

$$\sigma_a = 143\ \text{N/mm}^2$$

therefore $\alpha = 2.88$

In this example, it is found that the amplification factor equal to 2.88 thus showing an increase of 2.88 times the bending stress calculated from the program MAX.STRESS.

Table(22) gives the results from the MAX.STRESS program with slight changes to cater for the bending stress amplification. The final results do show some changes but the stresses on the members are within the safe limit.

6.4 ANALYSIS OF THE TUBULAR JOINTS

Almost all fixed steel offshore platforms have been of tubular frame construction with piled foundations. Tubular members are extensively used because their drag characteristics minimise the wave forces on the structure and their closed cross-section provides for bouyancy needed during installation in the open sea environment. Tubular members are also used in many truss type structures which require long slender compression members since the tubular cross-section exhibits a high strength-to-weight ratio.

In most instances, the connections of tubular members are

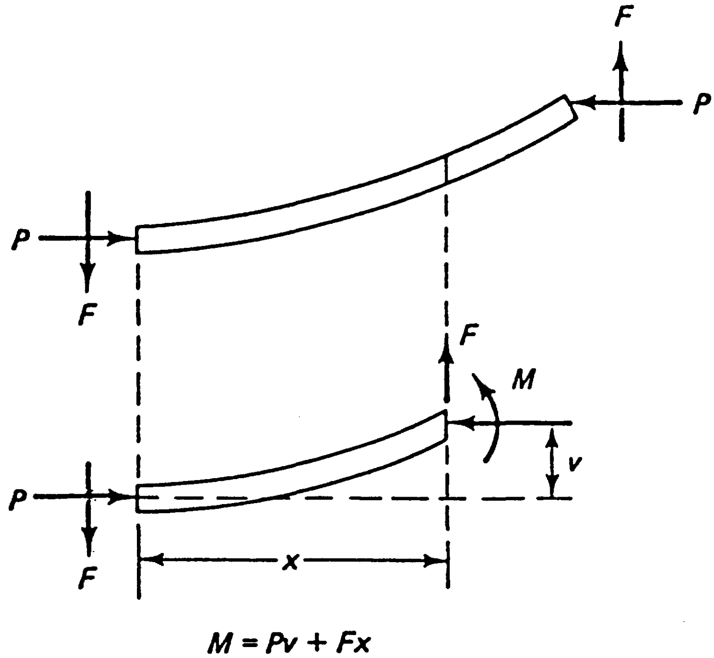


Fig.33 Moment Increases from Axial Loading

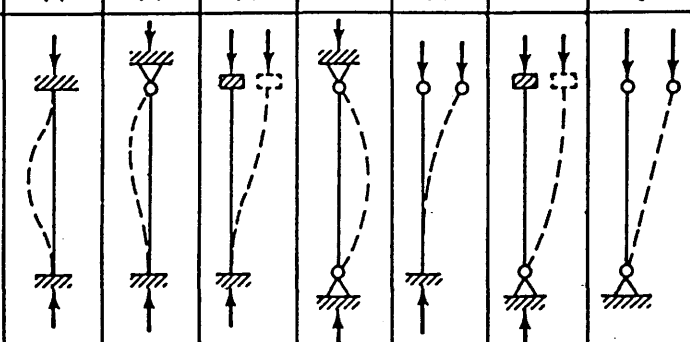
Case	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Buckled shape of column is shown by dashed line. The ends are assumed free to experience relative vertical movement.							
Theoretical K value	0.5	0.7	1.0	1.0	2.0	2.0	∞

Fig.34 Effective Length Factor

Table 21 : Member Stresses with Correction for Bending Stress Amplification

MEMBER	MAX. STRESS (kN/mm^2)	SHEAR STRESS (kN/mm^2)
1	0.1451	0.0725
2	0.1427	0.0717
3	0.1458	0.0729
4	0.1450	0.0725
5	0.1440	0.0720
6	0.1583	0.0792
7	0.1463	0.0732
8	0.1473	0.0736
9	0.1457	0.0728
10	0.1445	0.0772
11	0.1652	0.0826
12	0.1447	0.0724
13	0.1469	0.0734
14	0.1466	0.0733
15	0.1466	0.0733
16	0.1550	0.0775
17	0.1850	0.0925
18	0.1553	0.0777
19	0.1621	0.0811
20	0.1803	0.0901
21	0.1794	0.0897
22	0.1725	0.0862
23	-0.0109	0.0101
24	-0.0109	0.0101
25	0.0105	0.0100
26	0.0102	0.0099
27	-0.0118	0.0099
28	0.0086	0.0043
29	0.0015	0.0010
30	0.0040	0.0021
31	0.0066	0.0034
32	0.0066	0.0033
33	0.0091	0.0065
34	0.0112	0.0072
35	0.0201	0.0109
36	0.0209	0.0112
37	0.0111	0.0067
38	0.0124	0.0071

formed by full penetration, welding of carefully contoured ends of the branch members to the continuous chord of the truss. These joints are subjected to some considerable stress concentrations (hot spot stress) at the intersection of the chord and bracing walls. As the load increases, the material yeilds and redistribution of stresses occurs, until plastic deformations become visible and the joint finally fails.

The failure of a joint is commonly defined by the ultimate strength of the joint and this is generally accepted to be the maximum axial compressive (tensile) load, applied to the end of the bracing, at which the joint fails.

Depending on the type of joint, joint parameters and whether the loading is compressive or tensile, the following modes of failure can occur:

1. plastic deformation of the chord,
2. punching shear failure of the chord,
3. shear failure of the chord between the bracing,
4. lamellar tearing in the chord wall under the tension bracing, when the chord walls are very thick, and
5. local buckling.

Most tubular joints are designed on the basis of the punching shear stress. Only in special cases where there is reason to suspect the possibility of stability failure of the chord is collapse considered.

6.4.1 Punching Shear Stress

Under service loads, the forces in each cross members are seen to be transmitted directly to the wall of the leg. If the thickness of the wall is too small, there is a possibility that local shear failure on the surface of the chord would occurs before the ultimate strength is reached.

For an approximate analysis of the punching shear stress induced in the leg of the structure by a cross member, we may neglect the curvature of the leg and treat the problem as an inclined circular member connected into a flat plate as shown in Fig.(35). The perimeter of the intersection will generally be elliptical in shape, with its major and minor axis equal, respectively, to $2R_b/\sin\theta$ and $2R_b$. The punching shear τ_{pa} in the leg wall from force, F_x, is expressible as

$$\tau_{pa} = \frac{F_x}{tc}$$

Similarly, if M denotes the moment exerted on the leg by the cross member, the punching shear stress resulting from this moment is

$$\tau_{pm} = \frac{My}{tI} \qquad \text{where} \quad I = \int y^2 ds$$

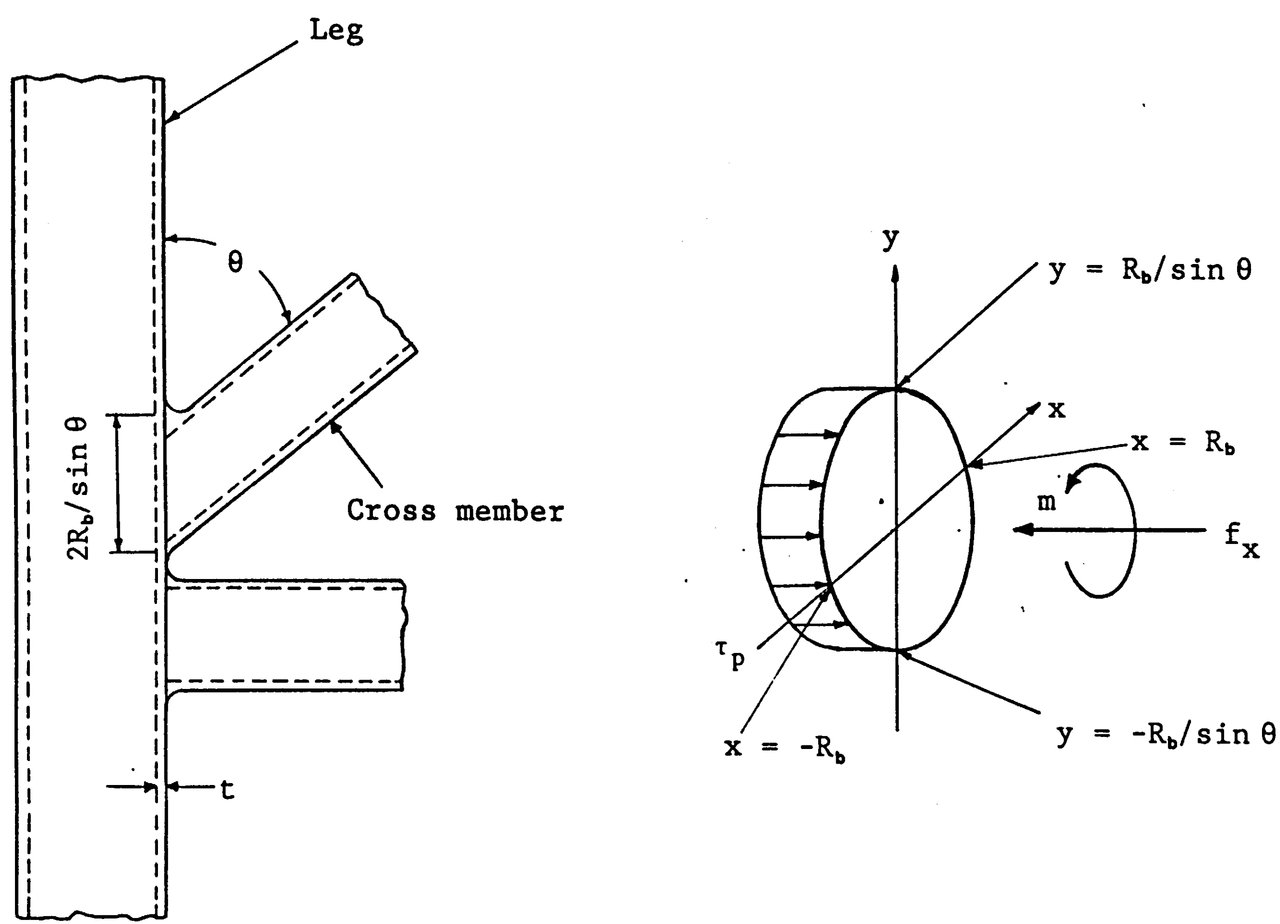


Fig.35 Joint Geometry for Punching Stress Analysis

where the extreme values occur at $y = \pm R_b \sin\theta$

Thus maximum punching shear stress,

$$\tau_p = \alpha_1 \frac{|F_x|}{2\pi t R_b} + \alpha_2 \frac{|M|}{\pi t R_b^2}$$

where α_1 and α_2 denote dimensionless coefficients depending only on the inclination θ of the cross member as indicated in Fig.(36).

To evaluate the punching shear stress of the structure under consideration, only joints 6 and 17 are taken into account.

Item	Joint 6	Joint 17
F_x (N)	34815.68	18309.40
M (Nm)	463139.40	186954.20
α_1	0.90	0.70
α_2	0.70	0.48
t (mm)	25.00	25.00
R_b (m)	0.50	0.50
τ_p (N/mm^2)	16.90	4.73

To ensure against punching shear failure of the joints, it is necessary that the stress be less than the shear yield stress of the

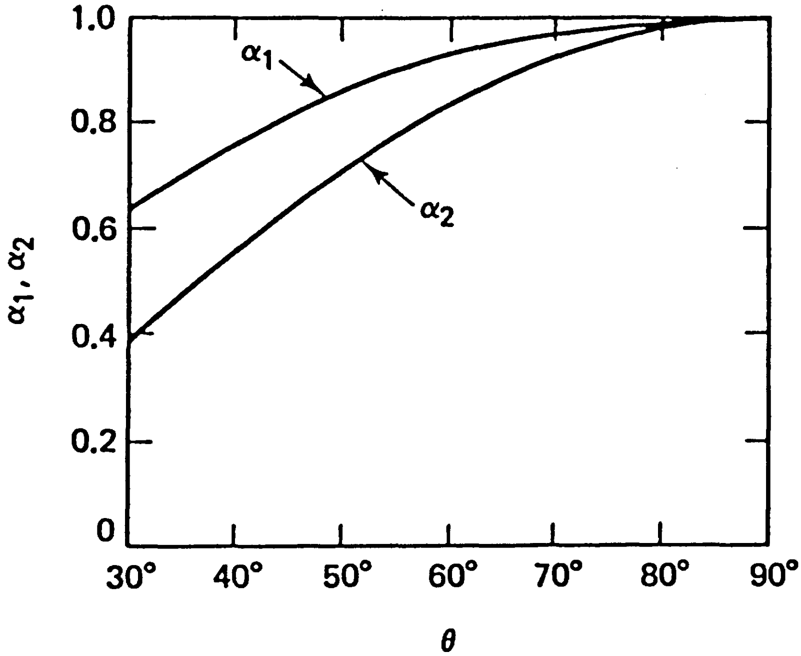


Fig.36 Shear Coefficients [46]

material, with a suitable factor of safety. This leads to a maximum allowable shear stress which is normally estimated as 0.4 times the tensile yield stress.

6.4.2 Fatigue Analysis

Fatigue can be described as the process of progressive localised permanent structural changes occurring in a material subjected to loading conditions, which produce fluctuating stresses and strains at some point or points which may culminate in cracks or complete failure after a sufficient number of fluctuations. The fatigue life is generally specified as the number of cycles of stress or strain of a specified character, that a given specimen sustains, before failure of a specified nature occurs.

The relationship between the stress or strain and the number of cycles is generally represented in S-N diagrams in which the stress or strain range is given on the vertical axis and the number of cycles on the horizontal axis, both on logarithmic scales.

6.4.2.1 Factors Affecting Fatigue Behaviour

There are many factors in which the fatigue life may be influenced; some of these will be discussed here.

6.4.2.1.1 Loading

The loading of offshore structure is a complex combination of forces from wind, waves, currents, and vertical gravity effects. These load effect together cause fluctuations in the stresses of the structure. Since the loading fluctuations are not always constant, the loading or stress spectrum have to be considered. The shape of the spectrum has a real influence on the endurance. In practical design, cumulative damage rules are generally used to describe the fatigue behaviour under spectrum loading as a function of the individual load cycles. A major uncertainty in fatigue loading arises from directional wave energy spreading which reduces the loading from the uni-directional assumption often made in design. Prevalent wave direction is also an important consideration

6.4.2.1.2 Joint detail

In predominantly statically loaded joints, local stress or strain concentrations are of minor importance due to redistribution of stresses by local yeilding of a ductile material, however, under fatigue loading the stress or strain concentration is the dominant factor.

It is well known that applied loads on tubular joints cause stresses at certain points along the intersection weld to be many times the nominal stress acting in the members. This multiplier applied to the nominal stress to reach the peak or maximum stress at the critical location (hot spot) is called stress concentration factor (SCF).

The stress concentration factor is different from one joint geometry to another and is a measure of the joint strength, but this means that for every type of joint and every loading case in principle a different fatigue behaviour exists. Therefore the most common approach is to determine the relationship between stress or strain range and the number of cycles to failure for a specific weld detail, independent of the geometry of the joint.

6.4.2.1.3 Material

High strength mild steels have a better fatigue behaviour than lower grade mild steels, especially in the low cycle range. These differences are smaller or even disappear for notched specimens, for example welded joints where high strength steel is usual, due to the greater notch sensitivity of higher grade steel.

6.4.2.1.4 Environment

In a corrosive environment such as sea water, the fatigue performance of a steel structure is worse than that of a steel structure in a less aggressive atmosphere. Corrosion fatigue is a complicated phenomenon in that the influence of the environment cannot simply be superimposed on the fatigue behaviour due to their interaction with each other.

Another complication is that there seems to be no endurance strength limit, and that even very small loading cycles have an influence on the total corrosion fatigue performance. To avoid corrosion fatigue good protection by coatings or cathodic protection is necessary.

6.4.2.2 Methods of Analysis

Several methods of analysis are used to describe the fatigue behaviour of tubular joints, either by deterministic or probabilistic approach.

The deterministic approach is based on knowing the height exceedence diagram, usually for one year. Then the relationship between the stresses at the hot spot and wave height is found and finally a cumulative stress damage curve is computed by plotting number of cycles versus stress range. It is generally recommended that the dynamic amplification factor is taken into account especially for structure in over 100 m water depth and sometimes this is obtained by computing the dynamic response of a simplified system instead of the response of the multi- degree of freedom structure. The cumulative stress history curve is thus obtained and in addition the stress concentration factors may be needed before comparing the S-N curves to failure so obtained with those given by the classification societies. This is done using Miner's cumulative damage rule,

$$(D) = \Sigma \frac{n_i}{N_i} \leq 1$$

If (D) is the accumulated damage occurring during one year, the

the proportion of cycles in a particular stress range. This proportion is then multiplied by the total number of cycles for the particular stress range under consideration. The same is done for all the cycles and one obtains a cumulative stress history curve for one year period. The following steps are similar to the deterministic method of approach.

6.4.2.3 Stress Concentration Factor

Stress concentrations in tubular joints are of three pricipal type:

1. Primary stress caused by axial forces and bending moments in brace and chord.

2. Secondary stress caused by local stiffness variations.

3. Secondary stress caused by abrupt geometrical changes.

The magnitude of the SCF will seriously influence the fatigue resistance, and knowledge of this factor is therefore essential. In contradiction with the defination of the SCF for simple detail, the SCF for tubular joints is defined in a different way. For joints made of hollow sections the SCF is defined as

$$SCF = \frac{\text{maximum hot spot somewhere in the joint at the weld toe}}{\text{nominal stress in the bracing at the intersection}}$$

For joints with more than one bracing member both bracings have total life of the structure is

$$\underset{\text{(in years)}}{\text{Life}} = \frac{1}{(D)}$$

For a probabilistic fatigue analysis one starts by considering the different sea states for a one year period and the percentage of time during which they act. The number of times a sea state produces peaks that exceeds a particular stress level can be computed from the distribution of stress peaks. For each sea state this distribution is fully defined by knowing σ_s (stress deviation at hot spot under consideration). The probability curve can then be plotted for each sea state against the stress level. The curve is a Rayleigh distribution if the process is narrow banded.

The number of cycles per sea state is calculated by determining the mean stress period.

$$T = 2\pi\left(\frac{m_0}{m_2}\right)^{\frac{1}{2}}$$

Hence the number of the cycles results,

$$N_s = \frac{T}{T_{ms}}$$

Note that the total area under probability curves is always equal to one. The area A for intance describes for each sea state to be considered.

In practical design the hot spot stress or strain has to be determined and it is time consuming to carry out finite element calculations for every joint. Therefore semiempirical parametric formulae have been developed to estimate the geometrical SCF at the weld toe for most common simple types of joints. All these formulae have the following functions

$$SCF = K.\ \gamma^{K_1}.\ \beta^{K_2}.\ \tau^{K_3}.\ g^{K_4}.\ \sin^{K_5}\theta$$

Fig.(37) is the required diagram for one of the joints of the structure. Thus for the structure being considered

$$SCF = 13.804 \times \gamma^{0.1}\ \beta^{0.36}\ \tau^{0.65}\ g^{0.126} \sin 90°$$

$$SCF = 15.19$$

Fig.(38) shows the S-N curves for the tubular joint as compared to the curve to failure from Bureau Veritas.

The cumulative damage ratio (D) is to be calculated by dividing the stress range distribution into a large number of blocks and applying Palmgren-Miner rule.

$$(D) = \Sigma \frac{n_i}{N_i}$$

$$= \frac{10^2}{10^7} + \frac{10^3}{10^{7.3}} + \frac{10^4}{10^{7.8}} + \frac{10^5}{10^{8.5}} + \frac{10^6}{10^{8.6}} + \frac{10^7}{10^{9.1}}$$

$$= 0.011$$

Thus,

$$\underset{\text{(in years)}}{\text{Life}} = \frac{1}{0.011}$$

$$= 91 \text{ years}$$

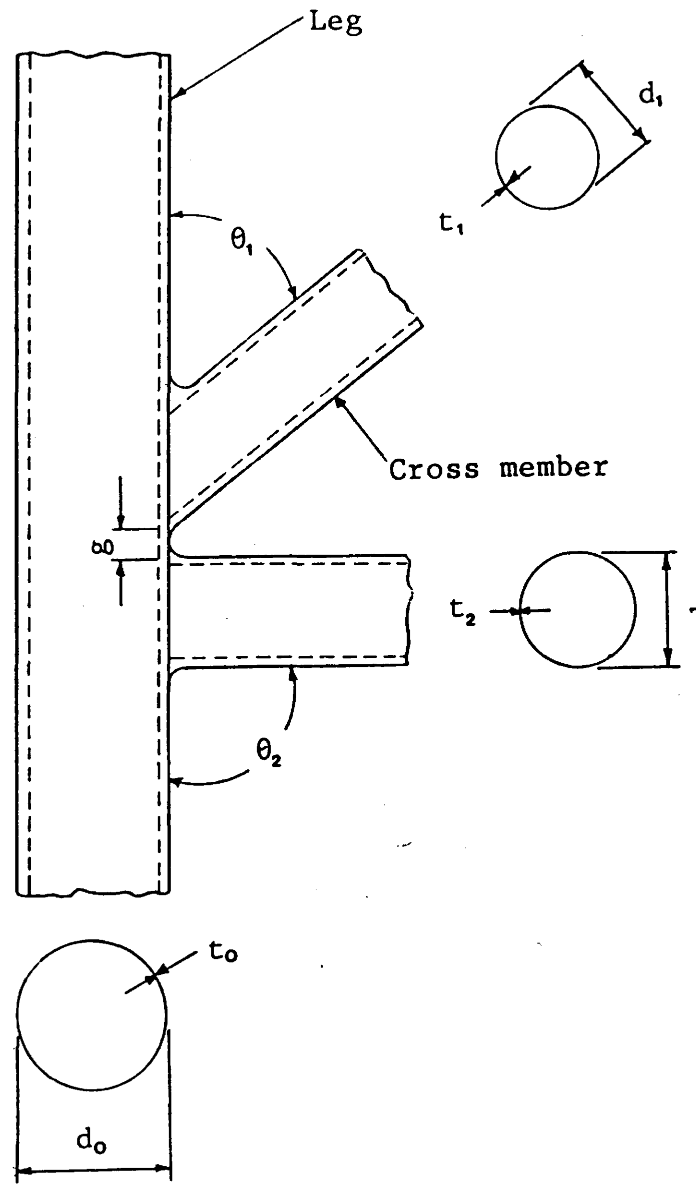


Fig.37 Joint Geometry for SCF Analysis

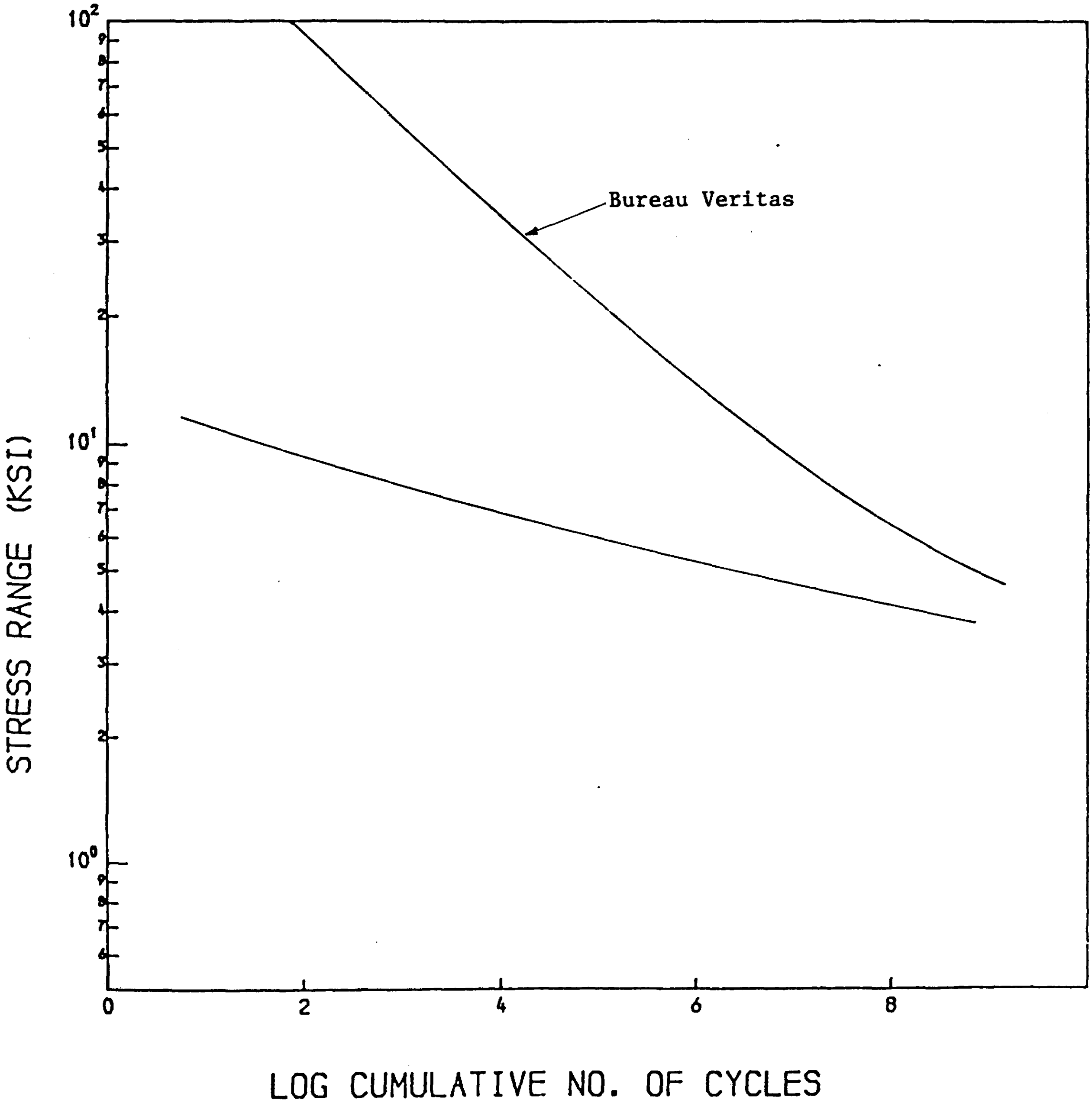


Fig.38 : S - N Curve

CHAPTER 7

THE EFFECT OF VARIATIONS IN DESIGN CRITERIA

7.1 INTRODUCTION

Most of the parameters used in defining the design criteria for offshore platforms are variables which are subjected to changes due to insufficient data and/or inadequate technology. In most design processes, guidance in the selection of particular values for the parameters are obtained from certifying agencies, onsite measurements, and operational requirements. Even though these parameters are produced through extensive studies and investigations, they are not absolute, thus enabling a range of designs to be possible. The objective of this chapter is to study the effect of variations in some of the more uncertain parameters on the fixed offshore platforms. This subject is often known as sensitivity analysis.

7.2 PROCEDURE

In order to study the effect of variations of the design parameters, a base case or reference structure is needed to use as a datum line. In this instance, the structure designed in chapter 6 will be used. The restraints imposed in this study are:

1. It must be based on a set of real design criteria.

2. No variations in the foundation, water depth and overall platform configuration.

3. An elastic design based on static loading.

4. One parameter varied at a time.

5. Increments of parameters were chosen to best show changes, whether in overturning moments and/or stresses as well as deflections.

7.3 ENVIRONMENTAL PARAMETERS

As was stated previously, the structure is not redesigned for each change in parameters. Only the change in overturning moment or stresses are determined by varying the parameters. The jacket put forward for the South China Sea was in a reasonable depth of water 80 m, has fairly large diameter legs of 2 m and the storm wave height of 7 m is modest by North Sea standards. Thus the ratio of the leg diameter over the wave height is about 0.285 and indicates that the inertia loads are likely to predominate. The starting values of C = 2.0 and C = 0.6 are quite usual but the fact that the vertical members of the platform are about a quarter of the wave length apart should be noted.

Table (22) shows the range of parameters investigated.

7.3.1 Wave Height

A wave height of 7 m with a corresponding period of 11 seconds was considered in the base case for design. Additional wave heights of 7.7, 8.4 and 9.1 m with the same 11 seconds period were investigated

Table (22) : Range of Parameters Investigated

Parameter	Base Case Value	Other Values Investigated
Wave Height (m)	7.0	7.7, 8.4, 9.1
Wave period (s)	11.0	12.1, 13.2, 14.3
Mass Coefficient	2.0	1.2, 1.4, 1.6, 1.8
Drag Coefficient	0.6	0.5, 0.7, 0.8
Marine Growth (mm)	0.0	0.0 to 150
Deck Loading ($x10^3$ t)	9.0	9.9, 10.8, 11.7

Fig.(39) shows the relationship between the wave height and the resulting overturning moment. Increase of wave height increases the overturning moment in direct proportion being the combined influence of inertia and drag forces.

7.3.2 Wave Period

A wave period of 11 seconds was considered in the base case and increments of 10% to 30% of this period are investigated along with the same wave height. Fig.(40) shows the effect of increasing wave period on the overturning moment. As expected, with the increase of the wave period, the overall overturning moment is reduced. This is because the water particle velocities are reduced thus reducing the inertia and drag forces.

7.3.3 Mass Coefficient (C_M)

A mass coefficient of 2.0 was used in the base case design. Additional values of 1.2, 1.4, 1.6 and 1.8 were considered. Fig.(41) shows the relationship between C_M and the resulting overturning moment. This relationship is almost a straight line where a 10% change in C_M will results a 11.1% difference in the overturning moment. This change indicates that the inertia forces are more significant than the viscous forces for the environmental regime considered.

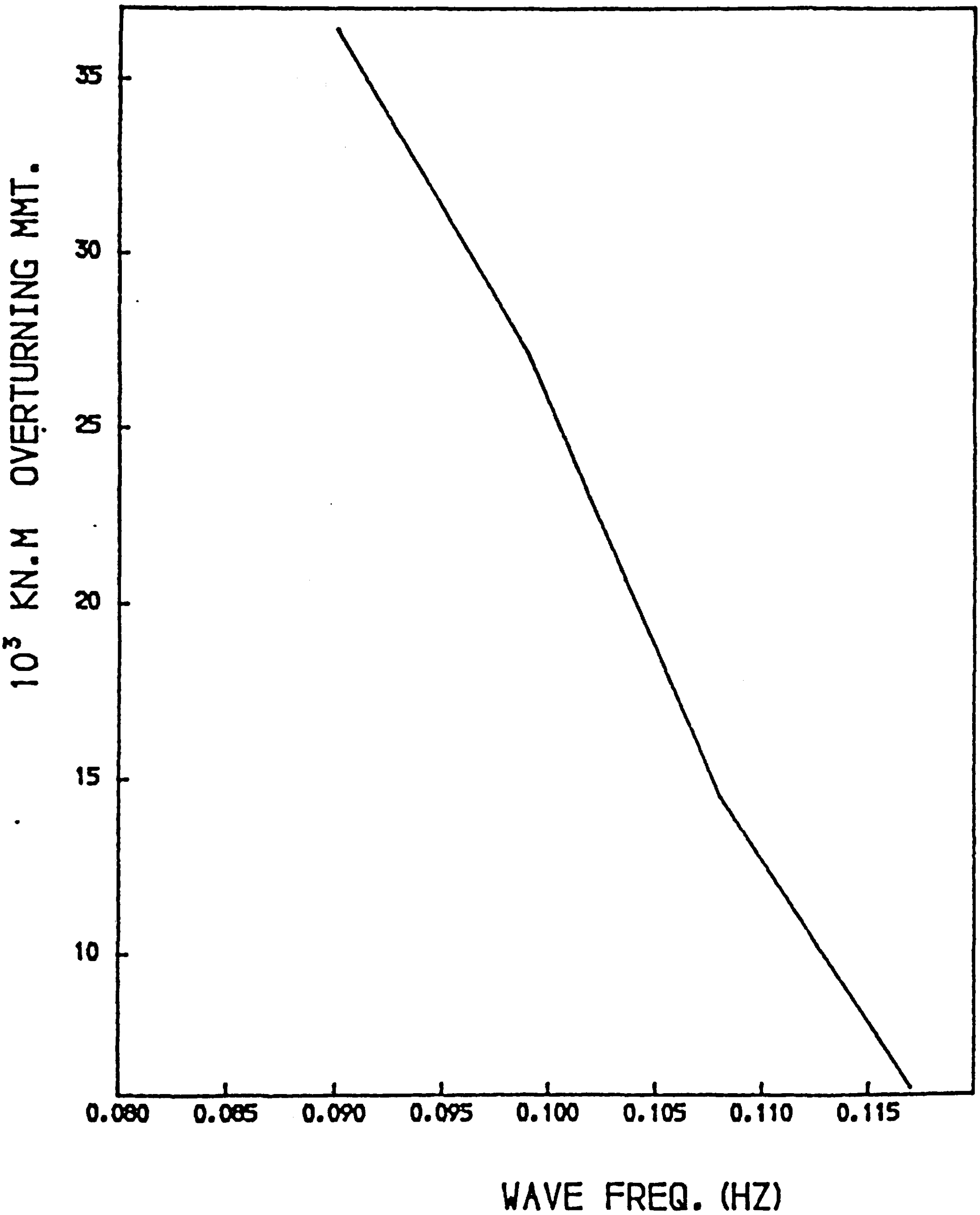


Fig.40 Effect of Wave Period on Overturning Moment

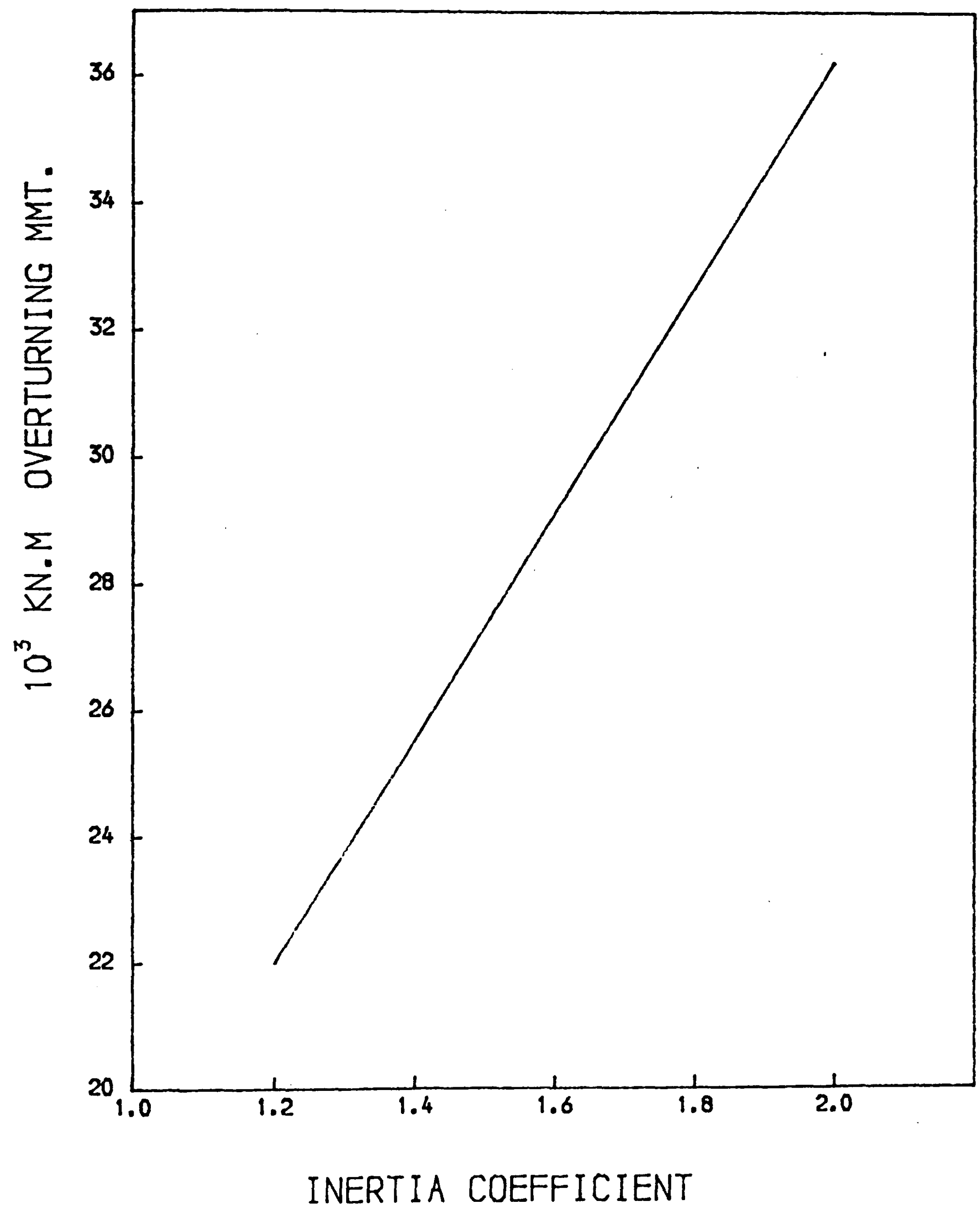


Fig.41 Effect of Inertia Coefficient on Overturning Moment

7.3.4 Drag Coefficient (C_D)

The base case was analysed using a drag coefficient of 0.6. Additional values of 0.5, 0.7 and 0.8 were considered for C_D. Fig.(42) shows the relationship between C_D and the resulting overturning moment. Increase in drag coefficient reduced the overturning moment but not in a pronounced manner. This would not be possible for a single column and in a structure is influenced by the separation of the columns. In this case when the inertia forces peak at one column, the drag forces at the other column are negative and increasingly so for the larger C values so as to reduce the total force. The small reduction indicates little sensitivity to C_D. In the usual North Sea condition, drag forces are more important than inertia forces.

7.3.5 Marine Growth

In the base case design, the effect of marine growth is not considered. In this study, values between 0 to 150 mm were taken as a fully effective increase in diameter. Fig.(43) illustrates the influence marine growth has on the overall overturning moment. An increase of marine growth from 0 to 150 mm added to the diameter results in an increase in the overturning moment of 0 to 22.2% change to the overturning moment.

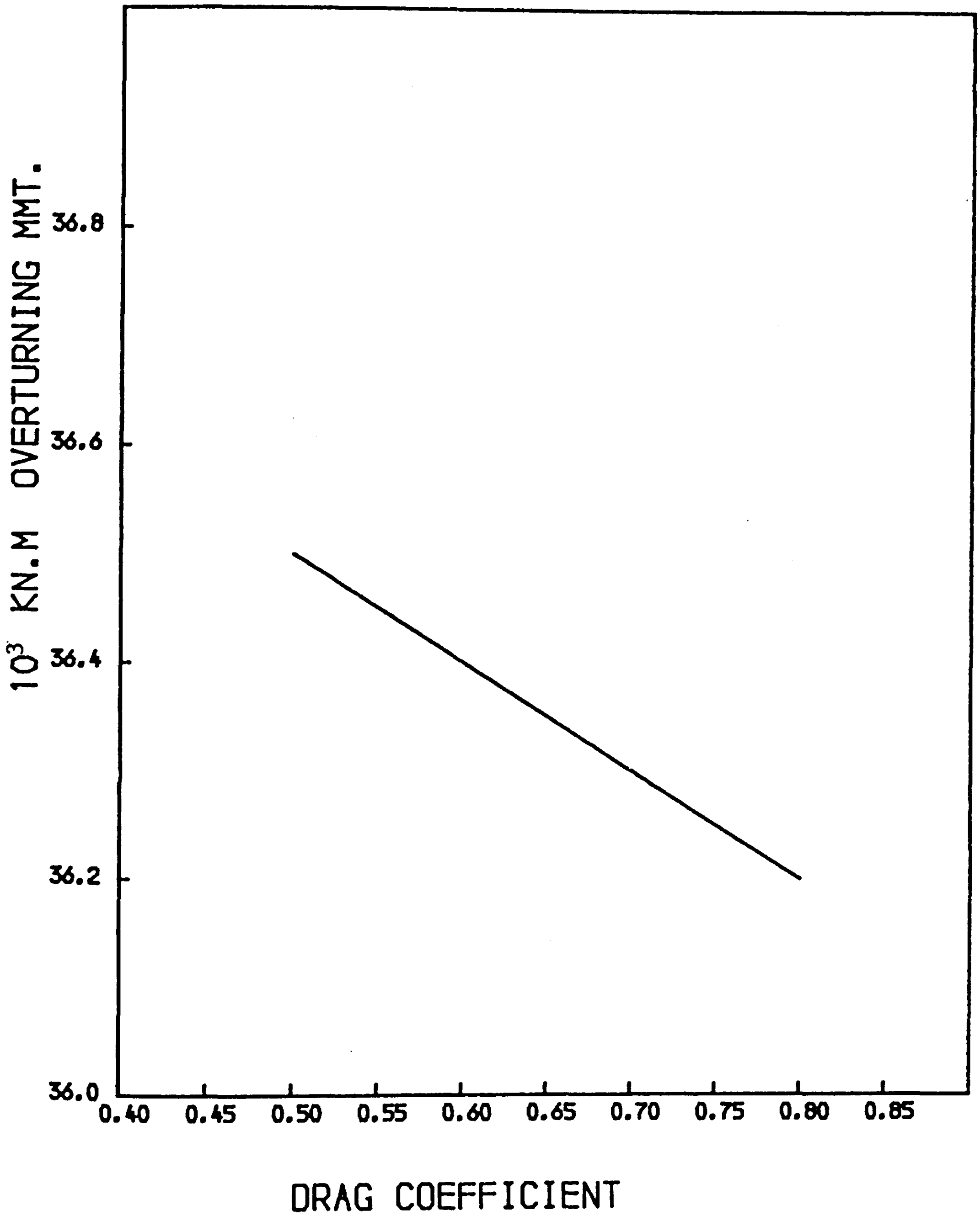


Fig.42 Effect of Drag Coefficient on Overturning Moment

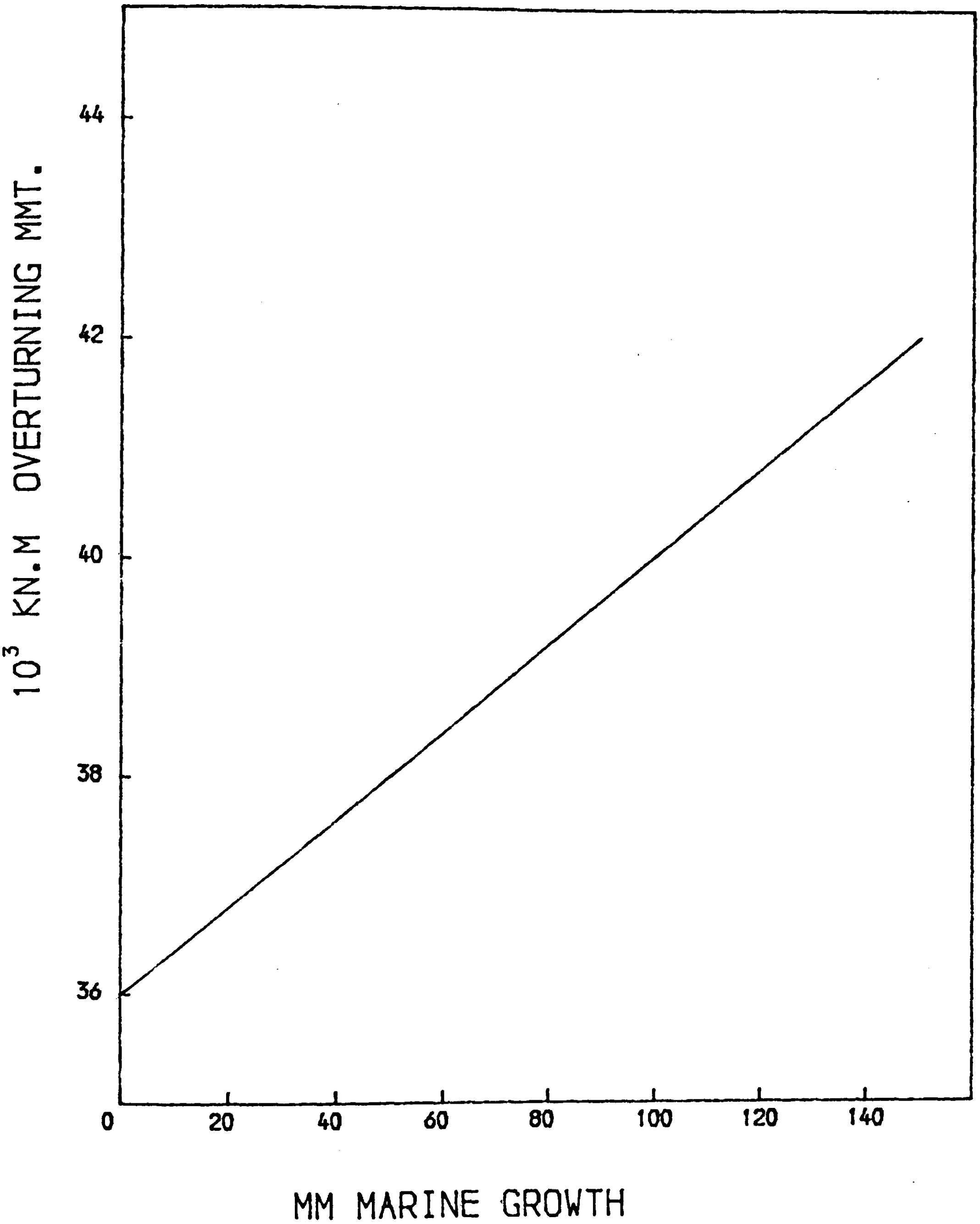


Fig.43 Effect of Fully Effective Marine Growth on Overturning Moment

7.4 OPERATIONAL CRITERIA

7.4.1 Deck Loading

The effect of deck loading predominates in this example where environmental loads are modest and is a reminder of the importance of deck mass and topside equipment reduction especially in the South China Sea.

There are two cases to be considered;

1. Equal increase of loading density on the four legs.

2. Increase in loading density on two legs only.

7.4.1.1 Equal loading density

In the base case, each leg carries a loading of 22000 kN and in this study this loading is increased from 10% to 30% in each leg. Fig.(44) shows the linear relationship between the deck load and the stress in the leg. As the deck load increases by 10% the stress increases by 11% or 14.5 N/mm^2.

7.4.1.2 Unequal loading density

In this case, only two of the four legs undergo an increased of 10% to 30% deck loading. The results show that the two legs experienced an increased of stress as in Fig.(44) while the other two legs maintained the original stress.

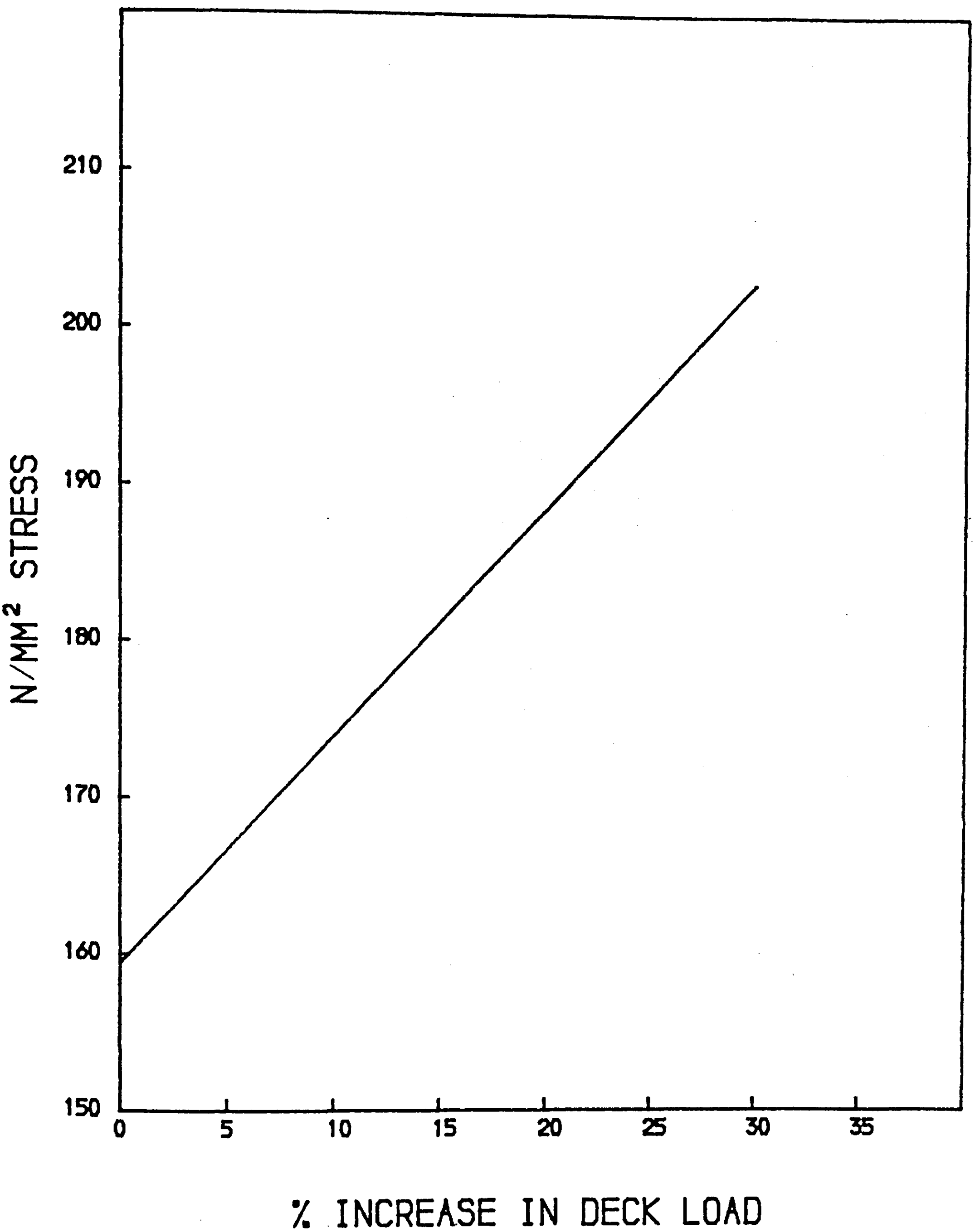


Fig.44 Effect of Deck Load on Member Stresses

CHAPTER 8

RECOMMENDATION FOR OFFSHORE ENGINEERING EDUCATION IN MALAYSIA

8.1 GENERAL

East and West Malaysia are substantial producers of oil and gas at the present time, mainly onshore but with a growing offshore production. In 1984, this production was 525,000 barrels of oil daily onshore and offshore. In a regional context oil and gas production is much greater when Indonesia, Brunei and Philipines are included while there may be substantial developments in Thailand and Vietnam. A developing industry requires personnel and in the middle and long term, personnel will be local nationals whatever expertise is brought in initially. Consequently, tertiary education in offshore engineering is a necessary part of tertiary education in Malaysia. It is attractive and it may be feasible to have a tertiary education centre for offshore work centrally located in the region but the first step is to implement the courses on a national basis.

8.2 A STYLE FOR THE COURSES

Tertiary education exists at sub-professional, professional and at postgraduate levels and all industries require this variation in level of expertise. Professional level is relatively easy to define as that of the first degree accredited by the Engineering Council in the United Kingdom and acceptable academically for the qualification of Chartered Engineer (CEng) and by appropriate bodies elsewhere. Earlier chapters have considered existing courses in Offshore

Engineering in the United Kingdom. At first degree level they are either sub-specialsations of education in Naval Architecture or sub-specialisation of education in the more mainstream engineering branches of Civil, Mechanical, Chemical, and Petroleum Engineering. It has been mentioned that the diffuse discipline of offshore engineering has no well defined professional engineering institution and this in part gives rise to sub-specialisation. In addition, if the offshore oil business is to be a sharply cyclical industry the individual may better retreat when required into his original specialisation although a sector with some offshore connections would be required. Such considerations indicate courses in offshore engineering which may be chosen or be selected after some years of education in other engineering branch specialisations.

8.3 A Role for the Malaysian University of Technology

The Malaysian University of Technology (UTM) has a remit for sub-professional, professional and postgraduate education in a wide range of engineering branches including Civil, Mechanical, Electrical, Petroleum, Chemical, and Marine. This makes it an excellent choice to mount courses in a new engineering specialisation by setting up an Offshore Engineering Department which will enable students to tranfer during their period of study from other branches. Since the usual length of sub-professional courses is three years and professional courses five years, there is scope to allow ultimate specialisation in Offshore Engineering at each of these levels. The present courses are conducted in semesters where there are two semeters of fourteen weeks each in a year. The present courses structure is given in Fig.(45).

8.3.1 Objectives of the Proposed Offshore Engineering Department

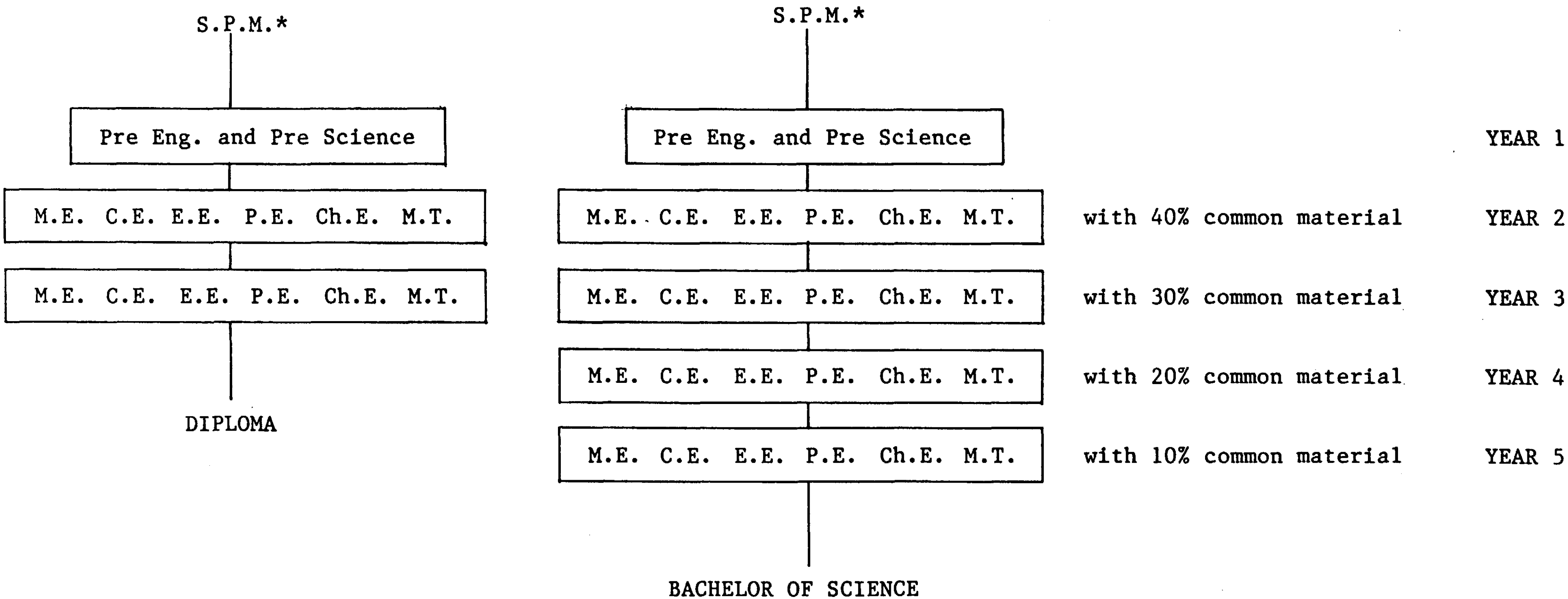
The objectives of the department may be as follows:

1. To provide education and training of manpower at all levels to meet the requirement of offshore engineering activities in Malaysia.
2. To conduct research and development in offshore engineering with special reference to the problems of the Malaysian offshore industries.
3. To provide an information data bank in all aspects of offshore engineering for application in Malaysia.
4. To conduct conferences/seminars and short courses on offshore engineering at regular intervals.
5. To have the potential to be an ASEAN centre for offshore engineering activities.

8.3.2 Course Philosophy and Aims

The philosophy of the courses should be based upon the premise that technological activities in the ocean environment require the normal understanding of engineering activities together with the ability to

Fig.(45) : Routes of Diploma and Degree in Engineering Education in UTM



* Equivalent to G.C.E. 'O' Level

M.E. : Mechanical Engineering

C.E. : Civil Engineering

E.E. : Electrical Engineering

P.E. : Petroleum Engineering

Ch.E : Chemical Engineering

M.T. : Marine Technology

conduct them offshore. First, a thorough understanding of the physical environment itself is essential, both qualitatively and quantitatively, in order to recognise and predict the conditions which will constraint any particular operation. It is then necessary to established the technology of any relevant activity in relation to the effects of this environment. This includes all projects involving offshore resources, from geological survey, through construction and operation of various types of fixed inatallation, to mobile activities associated with similar objectives.

The aims of the courses are necessarily broad to cater for the diversity of the offshore industry they serve. However, the ground base of the diploma and degree courses must be an adequate competence in an appropriate area of engineering. Thus the aims are:

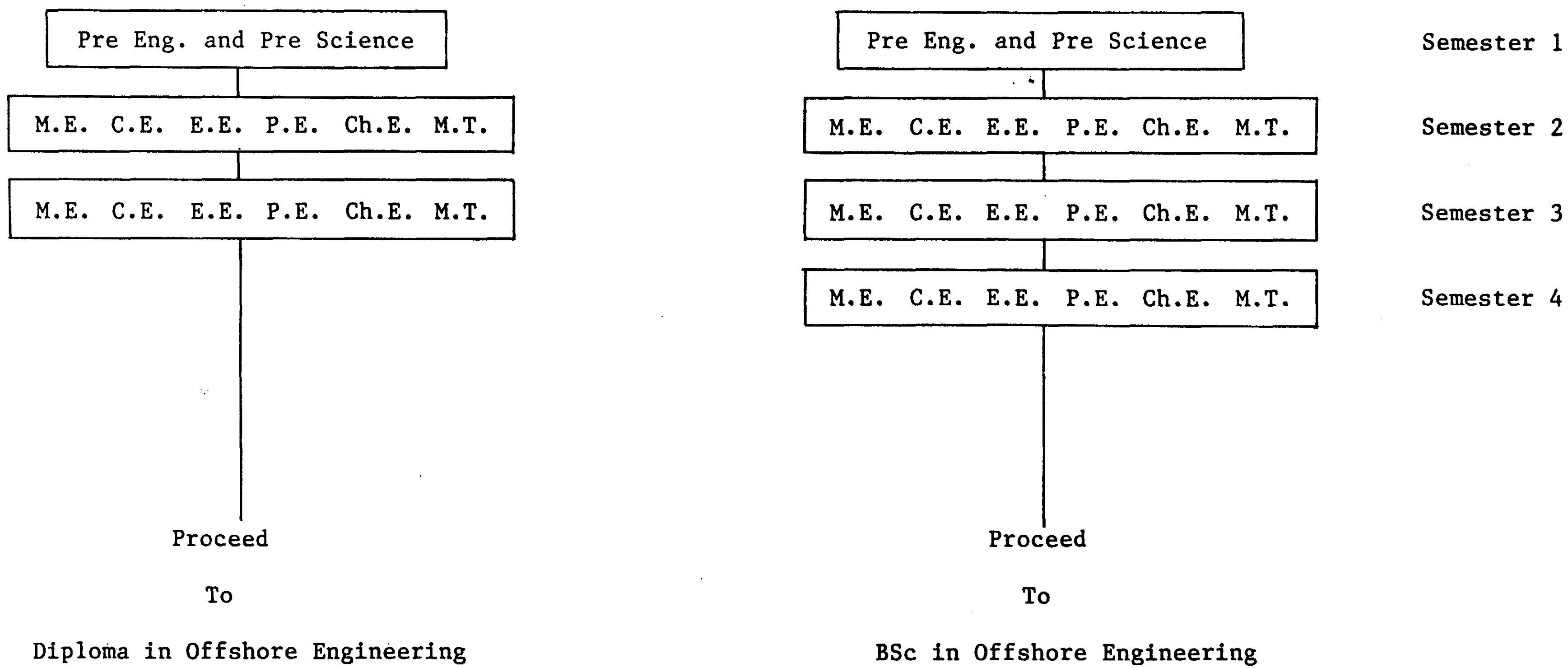
1. to provide a broad-based fundamental course for students who intend to become involved in the offshore industries.

2. to ensure that graduates understand, and are able to respond to, advances in technology and to changes in the operational environment.

8.3.3 Course Structure

To start with, the curicula of these courses may be borrowed from overseas institutions and gradually adapted to the needs of the Malaysian waters. Fig.(46) gives the recommended route for Offshore

Fig.(46) : Recommended Route to Offshore Engineering Education in UTM



Engineering education.

The course material is presented by lectures, seminars and project activities. Industrial specialists should also contribute to the programme of lectures and seminars. Industrial visits are integrated into the course structure. In the final year, students are required to carry out a project on an individual or group basis, which will represent a substantial commitment. The objectives of the project are:

1. to provide an opportunity for the students to integrate, as appropriate, various subject areas of the course within a specific problem area.

2. to encourage individual thought and initiative on the part of the students.

3. to gain experience of working as a group which is a very common feature of the offshore industry.

4. to provide an opportunity for the students to study selected research topics in depth.

To get a clearer picture, examples of the curicula for all the three levels are mentioned hereunder.

8.3.3.1 Structure of the Degree Course

The duration for the degree course is five years after ten or eleven years of schooling. Admission to the course is through one of the following engineering departments; Mechanical, Civil, Electrical, Petroleum, Chemical and Marine Technology. Fig.(47) gives the proposed breakdown of the material, in terms of percentage and number of hours of lectures, laboratory, tutorials and the time spent in the drawing office. The course contains throughout a substantial amount of material from any one of the engineering departments chosen for the first two years of study. This department is later referred to as the 'parent' department. In the third year, study of Offshore Engineering is introduced but a significant amount of time is still spent on studies in the parent department. In the forth year and subsequently fifth year, there is a decreased involvement with the parent discipline and about two-third of the time is devoted to studying Offshore Engineering subjects. This style is largely drawn from the course described in Chapter 2 Section 3.1, on the Heriot-Watt University. Table (23) gives the detailed breakdown of the offshore engineering subjects to be taken in the course.

8.3.3.2 Structure of the Diploma Course

The duration for the diploma course is three years after ten or eleven years of schooling. This course should be designed and introduced to meet an identified and growing demand for qualified personnel at sub-professional level in appropriate fields in offshore engineering. The students may follow a common engineering course as mentioned in the degree course structure during the first

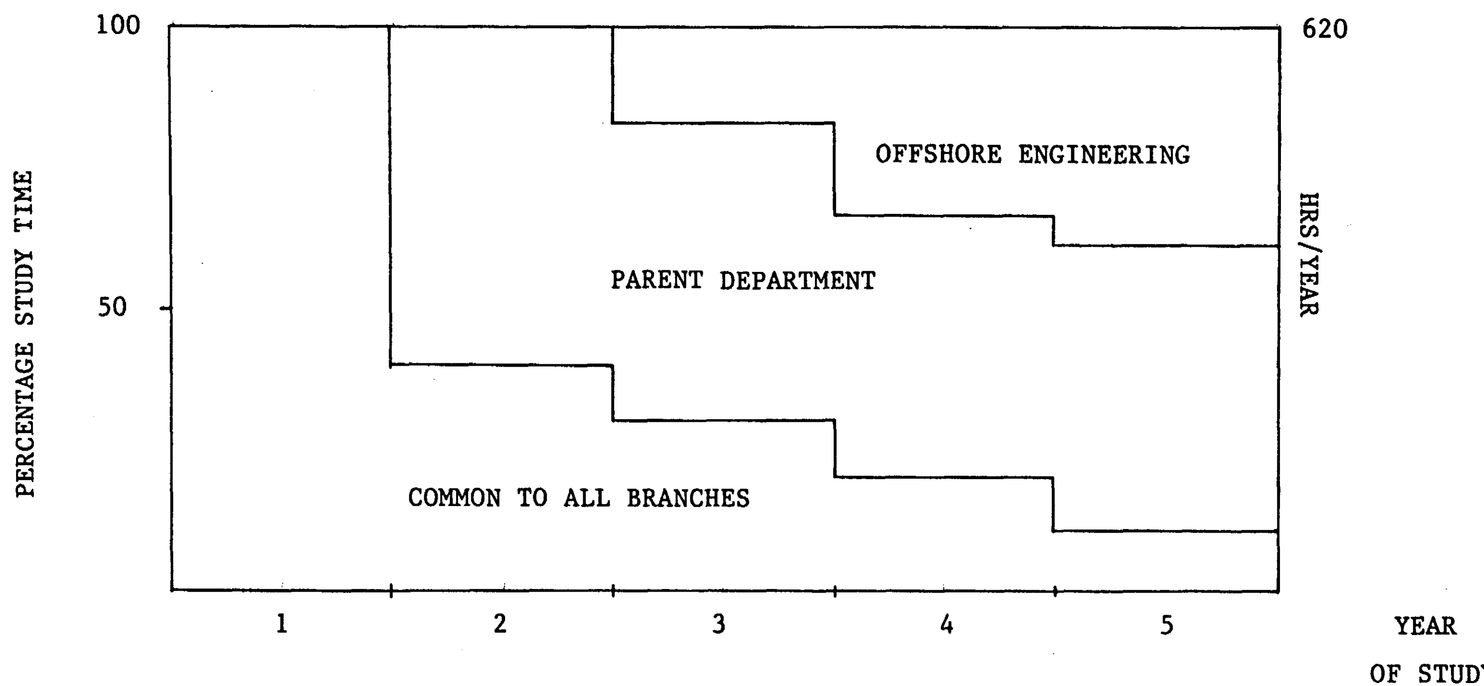


Fig.47 Material Allocation for the Degree Course

Table (23) : Offshore Engineering Subjects for the Degree Course

YEAR	SUBJECT	LECTURE/WEEK	LAB/TUT/DO
3	1. Introduction to Offshore Engineering	3	2½
4	1. Ocean Dynamics	2	} 5
	2. Marine Structures	2	
	3. Offshore Resource Recovery	2	
5	1. Design, Fabrication and Maintenance of Offshore Structures	2	} 2½
	2. Planning and Control of Offshore Structures	2	
	3. Project	NA	8

$1\frac{1}{2}$ semester and the remaining period may be invested for specialisation in Offshore Engineering as indicated in Fig.(48) and Table (24) gives the breakdown of the offshore engineering subjects to be taken.

8.3.3.3 Structure of the Master Degree Course.

The duration of the master degree course may be three semesters after a first degree in a offshore engineering. The students may follow advanced courses in offshore engineering and managerial subjects during the first two semesters and the remaining period may be invested for a project relevant to the offshore industry. The students may select any eight subjects from Table (25), two of which must be from the managerial topics. Candidates with a first degree in other branches of engineering or perhaps mathematics or physics should be acceptable but could expect a longer course, perhaps a further semester.

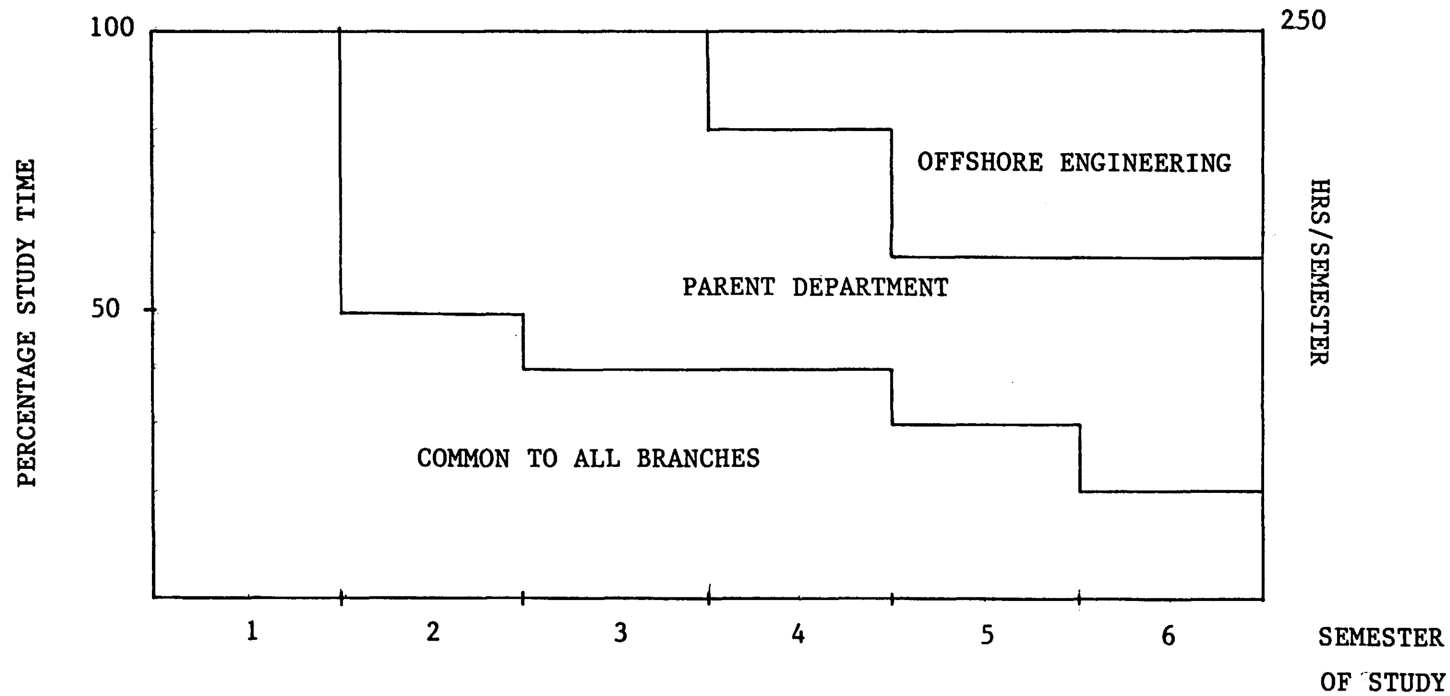


Fig.48 Material Allocation for the Diploma Course

Table (24) : Offshore Engineering Subjects for the Diploma Course

SEMESTER	SUBJECT	LECTURE/WEEK	LAB/DO/TUT
4	1. Fundamental of Offshore Engineering	2	2½
5	1. Fundamental of Reservoir Engineering	2	
	2. Introduction to Oil Production Tech.	2	} 5
	3. Offshore Structures	2	
6	1. Ocean Dynamics	2	} 5
	2. Offshore Instrumentation and Control	2	
	3. Group Projects	NA	6

Table 25: List of Subjects for the Master Degree Course

a. Offshore Engineering Subjects

1. Corrosion Engineering
2. Engineering Materials
3. Mechanics and Failure Analysis
4. Subsea Completion
5. Pipelaying
6. Transportation
7. Single Buoy Mooring
8. Articulated Columns
9. Risers
10. SWOPS
11. Diving and Underwater Operation
12. Reliäbilty Analysis
13. Inspection, Maintenance and Repair

b. Managerial subjects:

1. Project Management for Design, Fabrication and Installation
2. Structural Monitoring and Maintenance
3. Control of Oil Field and Oil Flow, Production and Delivery
4. Replenishment Arrangements
5. Quality Assurance and Quality System Assessment in Offshore Engineering

Syllabuses and Objectives of the Degree of Offshore Engineering Course

*3.1 INTRODUCTION TO OFFSHORE ENGINEERING

Objectives : To provide a basic understanding of the environmental, resource, technological and legal factors that contrain offshore engineering. Importance to be given to the full breadth of the subject.

Syllabus

a. Marine Environment

World Oceans, properties of seawater, winds, waves and currents. Geology of beaches, continental shelves and the deep ocean floor. Techniques of exploration for oil and minerals.

b. Resource

The oil industry onshore and offshore. Production, consumption, demand and trends. Impurities, refining and marketing variety of products. The rise of offshore oil.

c. Technological

Basic hydrodynamics, pressure forces on surfaces, bouyancy and floatation, ideal and actual flow of fluids. Statical stability of floating bodies, elementary resistance and propulsion of floating bodies. Introduction to fixed and floating structures. Diving. Underwater light, sound, magnetism. Cables, tools and machinery. Power sources. Materials and testing.

d. Legal

Law of the sea. Ownership of resources. National and international agreements. Inspecting and accreditation agencies. Engineering codes of practice.

* Year of Study. Course Number

4.1 OFFSHORE RESOURCE RECOVERY

Objectives : To provide an understanding of the engineering and organisation of offshore oil exploration and exploitation, and other commercial mineral recovery including the ability to perform design and calculation in these areas.

Syllabus

a. Petroleum Engineering

The oil field and reservoir engineering. Oil well, drill string, fluid flow, mud engineering, well logging, casing and cementing, blow out prevention and well control. Types of offshore exploration and exploitation marine risers and flowlines. Offshore processing and delivery.

b. Offshore Equipment

Drilling vessels, their types and capabilities. Prospecting and field development. Deck equipment. Production platforms and their requirements. Pipelaying vessels, pipelines. Crane barges, tugs, supply vessels.

c. Mining

Range of minerals. Vessels and techniques for recovery and processing.

4.2 MARINE STRUCTURES

Objectives : Study of the design and construction of fixed and floating structures to withstand the applied forces offshore. Consideration of their equipment, location and maintenance.

Syllabus

a. Fixed Structures

Type of structures and materials. Design consideration: design life, storm, tide and design wave, wave and wind forces. Codes of practice. Marine site investigations. Concrete and steel structures. Pile types and installation. Foundations. Analysis of frameworks. Computing techniques. Topside design and layout of equipment, mass estimation. Joint analysis: fatigue, punching shear. Corrosion. Seabed soil characteristics.

b. Floating Structures

Types and uses. Ship and semisubmersible hull forms. Design procedures and codes of practice. Introduction to steering, manoeuvring and motion characteristics. External pressure structures, design and testing of submersibles. Buoy systems. Tension leg platform and articulated column designs. Mooring.

4.3 OCEAN DYNAMICS

Objectives : Provision of detailed understanding of ocean waves, wind, tides and currents, the forces that they generate and the response of floating bodies to these forces.

Syllabus
----

a. Ocean Waves

Wave theory and statistical description of a seaway. Deep and shallow water waves. Calculation of wave properties: wave parameters, wave description, wave measurement, evaluation of wave parameters for design. Characteristics of a wind generated wave: wave forecasting, maximum wave method, wave spectrum methods. Effect of wave diffraction, refraction, currents, and tidal effects. Wind statistics and forces. Spectra analysis. Simulation of random waves. Wave loads on fixed and floating structures: Morison's equation, problems associate with the use of Morison's equation.

b. Vehicle Motion

Response of fixed and floating objects to seaway forces: heave, sway, surge, roll, pitch and yaw. Matching of motion characteristics: coupling. Motion of moored bodies. Elastic vibration of floating bodies. Dynamic response and propeller excited vibration.

5.1 DESIGN, FABRICATION AND MAINTENANCE OF OFFSHORE STRUCTURES

Objectives : The course concentrates on offshore structures of the steel framework type and aims to allow the student to design such a structure and appreciate the equipment fitted to it.

Syllabus

Choice of structures for an offshore oil field. Estimation of the topside equipment for desired flowrate. Design codes of practice. Design techniques, calculation of loading and analysis of the structure. Design and layout of deck and topside facilities. Material and welding. Fabrication considerations, transport to site and installation methods. Fatigue safety and reliability considerations. Inspection techniques. Structural monitoring including NDT. Maintenance and repair. Joints and special features. Protection and coating. Design consideration of articulated towers, and tethered buoyant platforms. Pipelaying.

5.2 PLANNING AND CONTROL OF OFFSHORE OPERATIONS

Objectives : to provide an understanding of the offshore industry from legal, economic, managerial and safety considerations.

Syllabus

Organisation of the oil industry. Project management to bring a field into production. Analysis of operation from licensing the field to exporting the production. Platform management techniques. Safety legislation and documentation. Taxation and business considerations. Ship charter parties, tonnage, certificates, ship handling, station keeping. Safety in poor weather conditions. Marine instrumentation, communications, weather forecasting. Underwater equipment. Personnel consideration, the offshore workforce, recruitment, training and control. Manpower planning and budgeting. Fire fighting and escape. Diving equipment. Hyperbaric chambers. Environmental protection from oil spillage. Supply of consumables.

Syllabuses and Objectives of the Diploma in Offshore Engineering

*4.1 INTRODUCTION TO OFFSHORE ENGINEERING

Objectives : To provide a fundamental understanding of the offshore engineering activities and contraints.

Syllabus

a. Offshore Activities

Exploration, development drilling, production, tranportation of energy resources and minerals. Law of the sea. Legislation. National and international agreements.

b. Oceanography

World oceans, seawater properties, currents and the sea floor. Beaches, continental shelves, deep ocean floor, sediments, deposits of commercial interest.

c. Basic Hydrodynamics

Properties of saltwater. Fluid statics. Pressure forces on surfaces, Buoyancy and Floatation. Flow of an ideal Fluid. Introduction to linear wave theory.

5.1 FUNDAMENTAL OF RESERVOIR ENGINEERING

Objectves : To develop the understanding of the processes involved in the formation and entrapment of oil and natural gas, together with a basic knowledge of the principles of reservoir engineering.

Syllabus

a. Geological Oceanography

Ocean boundaries, beaches, continental shelves, marine sediments. Origin and sources of energy resources and minerals.

*Semester. Course Number

b. Petroleum Geology

Origin and composition of oil and gas. Migration, accumulation and entrapment of pools, fields and provinces. Petroleum reservoirs; petrology and production horizons, petroleum prospects and the economic environment.

c. Reservoirs

Types of reservoirs; gas reservoirs, gas condensate reservoirs, undersaturated oil reserves. Reservoir drive mechanisms: gas cap drive, dissolve gas drive, water dive, combination drives. Reservoir fluid mechanics.

5.2 INTRODUCTION TO OIL AND GAS PRODUCTION TECHNOLOGY

Objectives : To analyse the principles and practice of oil and gas production technology, particularly in the offshore environment.

Syllabus

a. Drilling Technology

Drilling fluids: classification of fluids, properties and flow conditions. Flow of non-Newtonian fluids. Drilling systems and equipment. Drilling techniques.

b. Oil Production Systems

Types of wells and completion. Gas-oil ratios. Well effluent, separation equipment. Operation of separators. Multi-stage separations. Production and separation principles. Gas and water injection. Prime movers. Compressor units. Instrumentation for the control and safety of production operation. Methods of offshore storage. Tanker transportation. Oil and gas pipeline transportation.

5.3 OCEAN DYNAMICS

Objectives : To provide a basic understanding of ocean waves, wind, tides and currents, the forces that they generate on structures.

Syllabus

Ocean surface waves. Calculation of wave properties: wave parameters, wave description, wave measurement, evaluation of wave parameters for design. Characteristics of a wind generated wave: wave forecasting, maximum wave method, wave spectrum method. Directional effects. Application of known wave characteristics to offshore structures: evaluation of wave particle velocities and accelerations. Linear wave theory. Wave forces: Morison's equation, problems associate with the use of Morison's equation. Structure/water interaction. Wave reflection. Introduction to Stoke's, Solitary, and Cnoidal wave theories. Wind and current loading.

6.1 OFFSHORE STRUCTURES

Objectives : To establish a fundamental basis for a logical appreciation of the behaviour of structures in ocean environment.

Syllabus

Hydrostatics: Static stability for small and large angles of heel. Trim and heel for floating vessels. Free surface effects. Damage stability. Review (including concept, construction, foundation, installation, structural loadings and operational experience) of concrete structures, fixed structures, floating vessels, conductors and risers. Approving organisations, Rules, Standards, Design codes and Statutory Regulations. Materials. Welding. Pipelaying. Soil characteristics.

6.2 OFFSHORE INSTRUMENTATION AND CONTROL

Objectives : To provide an understanding of the instrument and control systems used in the offshore industry.

Syllabus

Oil surveying instruments, well logging arrangement, mud control, blowout sensing and prevention, process control for desalination and separation. Pumps and pump controls, electrical power generation and switchboards, remote tank telemetry. Communication equipment. Data acquisition and transmission methods, basic concept of sampling and multiplexing, linear and nonlinear encoding, analogue-to-digital and digital-to-analogue converters. Incorporation of microprocessor methods and control in offshore operation. Weather instrument. T.V. monitoring systems.

CHAPTER 9

CONCLUSION AND DISCUSSION

9.1 CONCLUSION ON OFFSHORE ENGINEERING EDUCATION

There was a general feeling that offshore engineering was multidisciplinary and that the attempt to cover all aspects in an undergraduate course would be inconsistent with professionalism. Reviewing the existing undergraduate courses in UK, offshore engineering education is considered to be a 'late-specialization' topic. Thus, however an undergraduate course is planned, it must be true that offshore engineering graduates will, by reason of the time devoted to his offshore subjects, be somewhat less well equipped in the traditional subjects than his civil, mechanical or any other engineering counterparts. It is suggested that this could be a disadvantage in the long-term, both to the man himself and to his employer.

A view often advocated says that education to chartered engineer status in one of the conventional engineering disciplines is an essential preliminary, to be accomplished before any significant steps towards specialization can be introduced. Specialization, on this view, is best introduced at the post graduate level, perhaps with an MSc course, or research, or with shorter special-purpose courses. The large amount of time required by this method is a drawback. It rejects the great benefits which can result from harnessing the student's enthusiasm for offshore engineering at an early stage in his course. It may also, especially on courses with no industrial period, render unavailable the strong directing and motivating effects of contact with real problems in industry. It also increases the time taken for an offshore engineer to become available for employment. Although this method does have advantages; including flexibility, and offers a possible route to the already qualified engineers involved in the offshore field, it is felt that, for the reason stated above, it is by no means a universal solution.

Accreditation requirements may influence any engineering course. Since the Engineering Council imposes accreditation through particular Engineering Institutions, the absence of an Institution devoted solely to offshore engineering means that accreditation must be done by existing bodies such as the Royal Institution of Naval Architects or the Institution of Civil Engineers or the Institution of Mechanical Engineers or a mixture of such bodies. Since the offshore industry embraces such a wide variety of disciplines, this situation is unlikely to alter and any undergraduate courses remain likely to be biased in the direction of at least one of the professional institutions. If the offshore industry turns out to be highly cyclical, as primary products and capital goods tend to be, then this bias will be essential to offer a variety of work when the offshore industry is weak.

Having to undergo a postgraduate course in such a field is not an ideal solution partly because of the duplication of material and additional time required. With exception of one or two courses, most of the existing postgraduate courses in offshore engineering or related topics may use material about half of which, has already been presented to any one student during his first degree course. The prime reason for this outcome is that these courses are offered to attract not only students with related background but also graduates of many other engineering disciplines. Often students from other branches of study such as mathematics, physics and zoology are accepted into the course. Obviously, this is not the case for any other engineering postgraduate courses where only those with the relevant background are accepted into the course. Thus any postgraduate course which involves students from diverse backgrounds must contain much material at a level which is more appropriate to undergraduate study. It is unreasonable to give an MSc to a student for a one year postgraduate course where about half of the material is at a level of current undergraduate courses in other disciplines especially if this is deemed part of acceptability for the qualification of Chartered Engineering or equivalent.

The postgraduate course should present a rather different situation, where presumably the offshore aspects are planned on a more solid and possibly consolidated basic undergraduate training. The difficulty of choosing the syllabus for a postgraduate course would seem to be selecting the correct emphasis. It could be aimed at providing general background and awareness, or it could be much more specific and aimed particularly at one or more specilized fields of endeavour. In either case, its value might be limited as in the former case the individual would still have a lot to learn in his chosen field of employment, whilst in the latter event the particular skills acquired might limit the employment possibilities.

Finally, it is believed that a well arranged undergraduate course with offshore engineering options would be appropriate provided that the graduates are given the chance to attend as many short courses as possible or given specific training on-the-job. The evidence so far is that the study of offshore engineering has considerable appeal, whether as the first step towards a career in the field or for its inherent attractions as one element in a broad engineering education. It seems to combine, for many students, the normal attractions of engineering with the excitment and challenge of a new and expanding field.

9.2 CONCLUSION ON THE DESIGN OF THE JACKET PLATFORM

The design study of a jacket platform considered the two main types of loading, namely operational and environmental, on as simple as a jacket framework as possible. There was no attempt made to quantify the loadings from other sources such as collision with attendant vessels, growth with age, or construction loads due to fabrication, transportation and installation.

The frame chosen needed to conform to a conveniently available program for the static frame analysis and in this simplification, it is accepted that the framework is not a configuration meeting the guidelines of the American Petroleum Institute [53].

9.2.1 Operational Loads

These loads are a mixture of the dead loads associated with the mass of jacket, deck and equipment, and the live loads associated with the use of the equipment. Generally, the dead loads will predominate and no attempt was made to quantify the live loads. Estimating values of the dead loads begin the design of a jacket and are usually based on existing platforms. A good deal of published information is available for North Sea platforms and this was used for prediction of the operational loads in the design study. The parameters that determine the operational loads include the field size, oil flow, oil-gas ratio, weather conditions, oil export system and the replenishment cycle. Oil company attitudes, political issues and the state of art considerations are also involved and it is difficult to give a logical explanation for some of the variations in the published information. However, the design study concerned a comparatively straight forward oil flow and location.

9.2.2 Environmental Loads

Environmental loads are imposed on the platform by natural phenomena including wind, current, wave, earthquake, ice and earth movements. In the location of the design study, only loads caused by waves and winds were considered.

The design wave approach was used to determine the maximum wave height and the corresponding period with an average expected occurence interval of fifty years. Linear wave theory was used in the hydrodynamic analysis of the jacket platform.

The inertia and drag forces were calculated using Morison's equation, but taking into account the relative positions of the different members with respect to the structure reference system. The hydrodynamic coefficients have a very important role in the process of the wave loading estimation. The more accurate these coefficients are determined, the more reliable will be the final results of the loading. In this study, values of C_M and C_D equal to 2.0 and 0.6 respectively were used. The effect of lift force on the structure was neglected.

Chapter 6 considers the geometry and analysis of the jacket frame. It is simplified below what would be approved to ensure adequate redundancy. In terms of mass of steel it can be considered as follows:

4 vertical legs - 2.0 m dia x 0.025 m thick x 85.0 m long

Volume $= \pi \times 2.0 \times 0.025 \times 85.0 \times 4$

$= 53.4\ m^3$

8 horizontal braces - 1.5 m dia x 0.02 m thick x 55.0 m long

Volume $= \pi \times 1.5 \times 0.02 \times 55 \times 8$

$= 41.5\ m^3$

8 inclined braces = 1.0 m dia x 0.015 m thick x 69.5 m long

Volume $= \pi \times 1.0 \times 0.015 \times 69.5 \times 8$

$= 26.2\ m^3$

If the mass should allow for enough braces to make the frame approved, a further 8 inclined braces and 4 diagonal braces would be needed. Thus,

12 further braces	-	1.0 m dia x 0.015 m thick x 69.5 m long
Volume	=	π x 1.0 x 0.015 x 69.5 x 12
	=	39.3 m^3
Total	=	160.4 m^3 or 1251 tonnes of steel

Allowing a factor 1.25 for brackets, diaphragms and flowlines;

= 1.25 x 1251

= 1563 tonnes say 1500 tonnes

One third of the above value could be taken as an equivalent deck load.

Before the static analysis can be done on any jacket structures, the ground or soil conditions should be investigated. Soil is a highly complicated material which exhibits among others, plastic, viscous, consolidation, hysteresis, and cyclic degradation characteristics. However, in actual cases, the pile-soil combination is said to exhibit non-linear stiffness characteristics and this is usually allowed by solving the problem iteratively using a set of non-linear springs at the mudline support points. In this study, the base of the jacket structure is assume to be restrained from any linear movements.

The whole structure has been analysed using a two-dimensional frame anlysis computer program and this was considered to be sufficient since the jacket structure is not battered. Of course, when more accurate results are desired, a full three-dimensional structural analysis must be employed.

The highest maximum stress achieved in the extreme weather conditions is 0.185 kN/mm^2 which is slightly lower than that given by Bureau Veritas (0.188 kN/mm^2).

Failures in welded tubular frames occur predominantly at the nodes or joints of the jacket structure. These are the most highly stressed regions and the nominal member stresses from the frame analysis do not reflect the true stresses which will effect factors such as punching shear strength and fatigue strength. In this study, a simplified method for calculating punching shear and fatigue strength have been analysed.

The results of the sensitivity analysis are given in Chapter 7 and follow expected trends although the respond to increase of C_D needs careful consideration.

9.3 Future Work and Recommendation

9.3.1 Survey on Offshore Engineering Education

The survey on Offshore Engineering education could be extended by:

1. Reviewing all the syllabuses of the non-Offshore

Engineering subjects in any Offshore Engineering courses.

2. Obtaining views from Offshore Engineering and related firms regarding education and training of Offshore Engineers.

3. Reviewing all the available courses in Offshore Engineering in Europe and North America.

9.3.2 Design of the Offshore Jacket Platform

9.3.2.1 Structural Configuration

The static analysis of the structure could be done more accurately with a 3-Dimensional program package. Further work could be done by evaluating the design to ensure that it can withstand the loadings associated with fabrication, transportaion to and installation at the offshore site.

There is a need to consider the overload resistance capacity of the structure as revealed in some of the clauses in API-RP-2A [53], such as overload and joint punching shear overload criteria. Two concepts are involved: one is to build a certain amount of reserve strength into the structure to allow for gross overloads, the other is to build in residual strength to allow for local failures. The concept is to allow some local overloads or failures to occur, but to:

1. prevent serious damage to the remaining structure,

2. prevent progressive failure, and

3. retain sufficient strength to prevent subsequent failure from a lessor event prior to repair.

The keys to designing for these criteria are careful selection of load paths and building in framing redundancies. The shortest load path will obviously be the most efficient in terms of the level of overall structure stiffness attained and in the amount of steel used. This can be done on the existing simple framework.

9.3.2.2 Soil-Structure Interaction

For the analysis of behaviour and load responses, the importance of a more accurate representation of the interaction between the structure and the piling system should be emphasized.

The load-response function of the piles is normally non-linear due to the non-linear soil behaviour, whereas the structural analysis of the jacket is based on linear-elastic behaviour. In general, a soil-pile system may be adequately modelled by replacing it with equivalent lumped springs, dashpots, and if necessary forces.

The vertical stiffness of a pile is often very difficult to calculate and it may be necessary to resort to any existing reliable results. For the horizontal stiffness, three factors need careful consideration. First, the interaction between pile and soil must be analysed, taking into account the typical decrease in horizontal subgrade modulus near the top of the pile. Second, the horizontal subgrade modulus may decrease with time as lateral motion of the pile causes permanent strains in the soil surrounding the piles. Third, scour can be important in increasing the effective length of unsupported piles.

In order to assess the soil-structure interaction in the structural analysis of a jacket platform, an additional subroutine in the static analysis computer program would be necessary to input the data required.

9.3.2.3 Topsides

Topside design is iterative, and good design results from proceeding through the basic chain of drilling considerations, process design, accommodation requirements, utility systems design, mechanical equipment selection, electrical and instrumentation design and fabrication and installation considerations. At many stages there needs to be appropriate feedback of reliable information. As with all iterations; speed of convergence depends upon good initial estimates and rapid processing of data.

The interaction of modules and deck structures for operational and environmental loading should also be investigated. The foolowing basic data must be developed for execution of the analysis:

1. flexibilty matrix of the deck structure,

2. stiffness matrices of the modules,

3. deck stucture deflection data the load case(s) under consideration.

The flexibilty matrix of the deck structure is a square matrix which gives deflections of all module support points corresponding to unit loads at those point.

The stiffness matrices of the modules are square matrices which give reactions at all module support points corresponding to unit deflections at the module support points.

The deck structure deflection data required is the vertical deflections at the module support points for the relevant load case(s) without consideration of interaction between modules and deck structures.

The above matrix and deflection data can all be developed with the aid of standard computer programmes. Once the basic data has been developed, analysis may proceed.

9.4 FINAL REVIEW

This study has examined some education programmes for the new branch of technology called offshore engineering. It has illustrated an aspect of the expertise required by a design study of an offshore jacket platform and it has proposed an education pattern for offshore engineering in Malaysia.

Perhaps in future the offshore engineer will be the dominant influence in his field as is the naval architect in ships. However at present offshore engineering is essentially the offshore oil industry. Unless the range of offshore engineering interests can extend to other resources, the main influence offshore will continue to be petroleum engineering. Thus offshore engineering must continue as a range of disciplines with no distinct branch of engineering and associated Professional Institution as a controlling influence.

During the year of this study, the price of oil has fallen sharply to about half its recent value. This is a remender that onshore oil with its low production cost is a major threat to offshore oil and that land based resources may yet have a considerable period of dominance over offshore resources; and only there is offshore engineering expertise vital.

However no state with a coastline can ignore the importance of offshore engineering fail to make some provision for education and training in this important area.

REFERENCES

1. SCHENCK, J.H.: 'Introduction to Ocean Engineering', McGraw-Hill Book Co., New York, 1975, pp 8-40.

2. INCECIK, A.: 'A General Method and a Computer Program to Calculate Wave Loading on the Circular Cylindrical Members of Fixed and of Floating Offshore Structures', Dept. of Naval Architecture and Ocean Engineering, Report No. NAOE-HL-80-19, University of Glasgow, 1980.

3. ELLERS, F.S.: 'Advanced Offshore Oil Platforms', Scientific American, Vol.247, No.4, 1982.

4. DAVIES, J.C.G.: 'Project Economic Evaluation and Conceptual Planning - The Differences Between Onshore and Offshore Projects', Offshore and Onshore Engineering Practices Compared Symposium, Glasgow, 1984.

5. SARPKAYA, T. and ISAACSON, M.: 'Mechanics of Wave Forces on Offshore Structures', Van Nostrand Reinhold, New York, 1981, pp 5-8 and 458-460.

6. LIGHTHILL, J.: 'Waves and Hydrodynamic Loading', Behaviour of Offshore Structures, Vol.1, 1979.

7. BEA, R.G. and LAI, N.W.: 'Hydrodynamic Loadings on Offshore Platforms', Offshore Technology Conference, Vol.1, 1978.

8. MILGRAN, J.H.: 'Waves and Wave Forces', BOSS, Vol.1, 1976.

9. GRAFF, W.J.: 'Introduction to Offshore Structures', Gulf Publishing Co., Houston,1981.

10. LEE, G.C.: 'Recent Advances in Design and Construction of Deepwater Platforms - Part 1', Ocean Industry, Nov. 1980.

11. LEE, G.C.: 'Recent Advances in Design and Construction of Deepwater Platforms - Part 2', Ocean Industry, Feb. 1982.

12. CHAPMAN, J.C.: 'Design and Construction of Offshore Structures', BOSS, Vol.1, 1979.

13. SHELL: 'The Petroleum Handbook', Elsevier Science Publishing Co., New York, 1983, pp 157-160.

14. BRITISH PETROLEUM: 'BP Statistical Review of World Energy', British Petroleum, London, 1980.

15. EISSLER, V.C. and MCKEE, R.E.: 'Offshore Production Operations', Journal of Petroleum Technology, April 1985.

16. JOHN, A.M.: 'World's Largest Platform Underway', Ocean Industry, Nov. 1977.

17. JACKSON, G.E.: 'Chemical Treatment and Process Equipment for Water Injection and Oily Water Treatment Systems Offshore and Onshore', Offshore and Offshore Engineering Practices Compared Symposium, IME and ICE, 1984.

18. CLOUGHLEY, T.M.G.: 'Problems with Offshore Structures Still Being Faced by Oil Companies', Proceedings of Oceanology

International Conference, Brighton, 1978.

19. SMITH, R.S.: 'Quick Estimates for Offshore Operational Loads', Oil and Gas Journal, July 1982.

20. HOGBEN, N. and LAMB, F.E.: 'Ocean Wave Statistics', HMSO, 1967.

21. HALEY, W.J. and BLAND, M.A.: 'Redistribution of Module Reactions Caused by Environmental Loading', Proceeding of European Offshore Petroleum Conference and Exibition, 1978.

22. HARRIS, D.: 'Environmental Criteria for Fixed Steel Platforms', Proceeding of Oceanology International, 1984.

23. KLITZ, J.K.: 'North Sea Oil', Pegamon Press, London, 1980.

24. SILVESTER, R.: 'Coastal Engineering 1', Elsevier Scientific Publishing Co., Amsterdam, 1974.

25. WARDENIER, J.: 'Hollow Section Joints', Delft University Press, 1982, pp 371-439.

26. NORDENSTROM, N.: 'Ocean Environment, Waves, Wind and Current Forces', International Symposium on Ocean Engineering Through Marine Technology, Det Norske Veritas, Oslo, 1971.

27. ABDELRADI, M.E.: 'Hydrodynamic Loading and Design Aspects of Offshore Jacket Platforms', PHD Thesis, University of Glasgow, 1984.

28. LOGE, P.G.: 'Offshore Production Facilities Recommendations for

a Simpler Approach', Proceedings of European Offshore Petroleum Conference and Exhibition, Vol. 2, 1980.

29. SMITH, T.R.G.: 'Linear Analysis of Frameworks', John Wiley and Sons, New York, 1983, pp 354-424.

30. INSTITUTION OF STRUCTURAL ENGINEERS: 'Offshore Structures', London, July 1976.

31. GALLIMORE, D. and MADSEN, T.: 'The North Sea Platform Guide', Oilfield Publications Ltd., Ledbury, 1983.

32. BUREAU VERITAS: 'Rules and Regulations for the Construction and Classification of Offshore Platforms', Paris, 1975.

33. BROWN and ROOT: 'Full-Height Deck Float-Out in New Topside Installation Plan', Offshore Engineer, April 1978.

34. CHEN, W.F. and HAN, D.J.: 'Tubular Members in Offshore Structures', Pitman Advanced Publishing Program, London, 1985, pp 55 - 70.

35. MARSHALL, W.T. and NELSON, H.M.: 'Structures', Pitman Publishing Ltd., London, 1982, pp 54-106.

36. INSTITUTE FOR STORM RESEARCH, University of St. Thomas: 'Weather Average and Sea States for Selected Offshore Areas', Offshore Engineer, July 1978.

37. BREBBIA, C.A. and WALKER, S.: ' Dynamic Analysis of Offshore Structures', Newnes - Butterworths Pub. Co., London, 1979.

38. JOHNSON, A.J.: 'Design in Relation to the Environment', Conference on Offshore Structures', Institute of Civil Engineers, London, 1974.

39. HUSLID, J.M., GUDMESTAD, O.T. and PAULSEN, A.A.: 'Alternative Deepwater Concepts for North Sea Extreme Conditions', BOSS, 1978, Vol.1.

40. HOGBEN, N.: 'Wave Loads on Structures', BOSS, Vol.1,1976.

41. HALLAM, M.G., HEAF,N.J. and WOOTTON, L.R.: 'Dynamic of Marine Structures: Methods of calculating the dynamic response of fixed structures subject to wave and current action', CIRIA, London, 1977.

42. ROREN, E.M.Q. and FURNES, O.: 'Performance of Offshore Structures - State of the Art', Institution of Metallurgists, (Autumn Review Course), 1976.

43. HARRIS, D.: 'Environmental Criteria for Fixed Steel Platforms', Oceanology International, 1984.

44. BUNCE, J.W.: 'The Intergrity of Platform Superstructures', Collins Pub. Co., London, 1985, pp 1-32.

45. LEE, G.C.: 'Design and Construction of Deepwater Platforms', Offshore South East Asia Conference, 1978.

46. DAWSON, T.H.: 'Offshore Structural Engineering', Prentice Hall Press, New Jersey, 1983.

47. GREGG, D.E., MARR, T.O., BOWLER, D.L., LAUREN, P.K., BEAMER, R.N. and HOUSH, D.F.: 'Murchison Project Preliminary Planning Organization', European Offshore Petroleum Conference and Exhibition, Vol.1, 1978.

48. GEORGE, H.R.: 'The Role of the Department of Energy in the Safe Development of the UK Offshore Oil and Gas Resources', European Offshore Petroleum Conference and Exhibition, Vol.1, 1978.

49. LAVERS, B.A.: 'The Management of Large Projects - A View from the Oil Industry', 'Oracle 85' Symposium, 1985.

50. 'Training: Government, Universities and Industry All Involved', Offshore Engineer, February 1978.

51. 'Education and Training for Offshore Development, an Interdepartmental Working Party Report,' Department of Employment, 1973.

52. BISHOP, R.E.D., PENDERED J.W. and TAYLOR, R.E.: 'Education in Offshore Engineering', Symposium on Education and Training for Naval Architecture and Ocean Engineering, RINA, 1976.

53. 'Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms', API-RP2A, Dallas, TX, 10th Edition, Mar. 1979.

54. 'Ocean Engineering Teaching at the University Level', UNESCO Report on Marine Science (No.25), 1982.

55. OWEN, C.G.:'Meeting the Changing Demands for Offshore

Occupation', Oceanology International, 1978.

56. STARINK, A.:'Selection and Training of Engineers for Offshore Industries', Oceanology International, 1978.

57. STEPHAN, C.R.:'Ocean Engineering Education at the Undergraduate Level', Oceanology International, 1972.

58. MOAZZEM, H. and MOHD.AFIFI, A.M.:'The Possible Role of UTM in Supporting the Offshore Engineering Activities in the ASEAN Region', Seminar on Offshore Technology Malaysia, Feb. 1985.

59. McDOWELL, D.M.:'Postgraduate Education in Ocean Engineering', Oceanology International, 1972.

60. ROBERT GORDON'S INSTITUTE OF TECHNOLOGY:'Report for Renewal of Approval for the Postgraduate Diploma (CNAA) in Offshore Engineering', April 1982.

61. ADYE, A.M.:'A Preference for Graduates or Postgraduates with Degrees in the Traditional Disciplines Who Can be Trained "On the Job"', Oceanology International, 1972.

62. ALMAR-NAESS, A.:'Fatigue Handbook-Offshore Steel Structures', Tapir Publishers, Norge, 1985. pp 313-363.

63. Curricula in Offshore Engineering or Related Courses : Glasgow University, Heriot-Watt University, University College London, Newcastle Upon-Tyne University, Sunderland Polytechnic, and Cranfield Institute of Technology.

APPENDIX A

SYLLABUSES OF OFFSHORE ENGINEERING SUBJECTS OF INSTITUTIONS DISCUSSED IN CHAPTER 2

BEng in Offshore Engineering

THIRD YEAR

1. Environment and Design

Hydrostatics, Physical Oceanography, Wave Mechanics, Fluid Loading, Dynamic Systems, Environment/Pollution Aspects, Behaviour of Materials in an Offshore Environment, Fatigue, Materials for Offshore Structures, Marine Biology and Ocean Engineering.

2. Measurement and Control

Principle of Electrical Engineering, Offshore Navigation and Control, Non-Destructive Testing, Maintenance and Repair.

3. Offshore Engineering Laboratories

Several laboratory exercises are set in the third year and students are required to attend each one. In addition a written report must be submitted on each laboratory exercise. Although the labortory reports are not considered in the final assessment, progress to the final year of the course will not be allowed unless satisfactory reports have been submitted. Laboratories at present consist of the following topics: Offshore Cranes, Tension Leg Platforms, Flow Measurement, Wave Experiments, Quality Assessment of Concrete Coatings, Welding, Logic, Tranducers, Light, NDT, Corrosion and Offshore Materials.

FOURTH YEAR

1. Offshore Engineering IVA

Design criteria, certification, wave/structure interaction, static and dynamic analysis of fixed offshore structures, foundation analysis, design of piles, probabilistic analysis, diffraction effects, wave loading on concrete structures, dynamic analysis of concrete gravity structures. Analysis of simple floating structures.

Economic appraisal of petroleum projects, cash flow models, discounting, rates of return, sensitivity analyses, Monte-Carlo simulation. Decision trees, critical path method and PERT.

Offshore Moorings: Design criteria, Mooring applications. Catenary moorings. Neutrally bouyant moorings. General mooring problems (Pode's equation). Properties of man-made mooring materials. Effect of mooring elasticity. Cable wave equations - surface following bouy, free end loads.

2. Offshore Engineering IVB

FLUIDS: Review of sea loads on fixed structures; drag and inertia domination. Morison's equations. General equations of fluid motion; dimensional analysis, non-dimensional parameters. Wind loads on structures; masts, towers, lattice frameworks; aerodynamic admittance.

Waves: Water waves; potential theory; particle velocities; energies; standing waves; bottom pressure; energy extraction.

Wave Forcasting: Bretschneider and Piersen chart methods; wind profile over the sea; spectral formulation for describing sea states; Piersen-Morkowitz, Bretschneider, JONSWAP, Voznesenski-Netsvetayev spectra; directional spectra. Group velocity, phase velocity, dispersion. Wave refraction and shoaling.

Data processing: PDFs, correlation function, Fourier transform, FFT, cross spectral density function. Response of linear systems to excitation. Impulse response method. Convulation theorem.

Dynamics: Dynamic problems leading to ODEs. Up to three degree of freedom. Damped, forced, simple, harmonic, oscillatory. Lagrange's equations. Many degree of freedom. Matrix methods, Eigenvalue methods. Numerical solution of ODEs using Newmark-beta. Modal vibrations of cables and risers. Rayleigh's method. Rayleigh-Ritz method. Example computation of three degree of freedom system using various methods. Oscillations on non-linear systems.

Critical appraisal of Morrison's equation. Further aspects of energy methods in dynamic - Hamilton's principle.

3. Offshore Engineering IVC

A number of options are given, each of 15 lectures in length, and the student must attend at least four making 60 lectures in all. Options offered at present are as follows.

Pipeline

Methods of laying pipelines. Static analysis, catenary analysis. The effects of surge and heave using pseudo-static analysis. Stress calculations for pipelines lying on the sea bed, e.g. trenching, pipelines suspended because of scour, etc. Buckling. Protection, burial, corrosion.

Corrosion Engineering

Corrosion Mechanism: General attack, stress-corrosion, pitting and crevice corrosion, freeting and other chemical/mechanical mechanisms.

Corrosion Science: Basic thermodynamics and kinetics of corrosion leading to principles of corrosion protection by material selection, cathodic protection, coating and inhibition.

Corrosion in Marine and Petroleum Production Environments: Corrosion protection in marine environment. Cathodic protection, coatings, noble metal cladding. Petroleum production environments. 'Sweet' and 'sour' corrosion. Water-injection and seawater handling systems. Corrosion of steel embedded in concrete.

Marine Risers

Drilling and Production Risers: Rigid and flexible, integral and non-integral. Alternative Riser Systems: Articulated tower, SALS, etc. Top Connections: Multiproduct swivels, emergency disconnects. Bottom Connections: Flexible joints,etc. Riser Base Sections, Wellhead Arrangement: Single well satellite systems, modular, template, unitised template, wellhead chamber. Installation of Rigid and Flexible Risers. Riser Pipeline Connection Techniques: Clamps, J-tube, Bending shoe, Guide shoe, Riser Failure modes. Static Analysis of Marine Risers: Effective tension, effective weight, equilibrium equation, static solution of heavy cable, static solution of simply supported beam cable. Dynamic Analysis Methods of Marine Riser Systems: Riser analysis techniques.

Environmental Considerations

Impact of offshore oil technology on the biological environment, ecosystem energetics, phytoplankton, zooplankton. Tanker problems: spills contigency planning.

Petroleum Engineering

Introduction: Developing a reservoir.

Geology and Formation Evaluation: Origin and nature of reservoir rocks; origin and accumulation of petroleum fluis; formation evaluation.

Drilling: Introduction to rigs and rig equipment; drilling a well; drilling from floating rigs.

Reservoir Engineering: Fluid in the reservoir; reservoir drive mechanisms.

Production Technology: Well completion philosophy; basic completion equipment; review of typical completion systems; offshore production facilities.

4. Group Project

A group design study is undertaken. Reports will be submitted on the project and these will be considered in the final assessment as equivalent to 1½ written papers.

5. Individual Project

An individual project is undertaken. A report will be submitted on the project and this will be considered in the final assessment as equivalent to ½ a written paper.

6. Coursework

Certain pieces of coursework are set in the final year linked with Offshore Engineering IVA and Offshore Engineering IVB and written reports will be submitted which will be considered in the final assessment as equivalent to one written paper.

UNIVERSITY OF GLASGOW

BSc in Naval Architecture and Ocean Engineering

1. Ship and Ocean Structures III

Loading on structures, still water and wave bending moments, longitudinal, transverse and local strength, classification society requirements, shear and torsion of ships.

2. Ship and Ocean Hydrodynamics III

Dimensional analysis, components of resistance, model tests, model-ship extrapolation, friction lines, hull efficiency elements, methods of propulsion, propellers, geometry and design, cavitation, power estimation, service performance.

Wave theory including statistical description, introduction to motion of floating bodies and vibration of floating bodies.

3. Ship and Ocean Dynamics IV

Generation of waves by wind (speed, energy, pressure relationships), effects of shallow water, refraction, wave spectra, statistics of ocean waves; currents, tidal effects. Forces on structures in waves, body motion of free floating and moored bodies. Elastic vibration of floating bodies, dynamic response, propeller excited vibration.

4. Ship and Ocean Structures IV

Linear elastic analysis including instability in plates. stiffened panels, grillages and multi-cells structures, plastic bending of beams, introduction to stiffened tubes, interaction failure methods, safety concepts, synthesis of columns and stiffened panels, introduction to finite element methods.

Consideration of typical elements in ship and ocean structures, summary of deterministic and statistical treatment of wave loads, ductile and fracture modes of failure, variability of materials and fabrication, statistical approach to strength and primary safety, structural discontinuities, material selection, the design process.

5. Oceanography IV

Sea and Ocean properties. Theory of tides and tidal variations. Oceanic wave climate. Wave generation, propagation, refraction and diffraction. Oceanic geomophology and Ocean Currents. Aspects of wave, tidal, current and thermal energy utilisation. Exploitation of biological and mineralogical marine resourses.

SUNDERLAND POLYTECHNIC

BSc in Nautical Studies

SECOND YEAR

1. Marine Environmental Studies

Defination of atmosphere and hydrosphere. Behaviour of ocean/ environment. Hydrostatic and motion equations. General circulation of atmosphere. Theory of water waves. Modelling technique for atmosphere and ocean. Tidal prediction. Forecasting techniques.

2. Offshore Resources

The Earth: Internal structure; earthquake and igneous activity.

Petroleum Geology: Stratigraphy, Geological Structure, Petroleum; origin, composition and regional variation, Detailed study of the geology of offshore oil and gas fields.

Exploration in the Marine Environment: Position fixing for survey and site location purposes on the seabed. Geophysical techniques. Seabed mapping for geotechnical purposes.

3. Marine Structures

Load acting upon floating structures, structural requirements, local strength, structural failure, vibration, structural steels, mechanical behaviour, corrosion behaviour, failure of materials.

3. Law

Introduction to international law. The law relating to offshore operations. Carriage of Goods. Insurance. Contract and liabilities. Arbitration.

4. Design of Marine Vehicles.

Design criteria and requirements. Design methodology. Propulsive devices. Safety and stability.

5. Marine Structures and Dynamics

Structure types and systems. Structural analysis. Structural assessment and design. Structures and materials. Lateral wave loading. Wave statistics. Wave spectra. Surface body behaviour. Handling.

THIRD YEAR

1. Marine Structures

Load acting upon floating structures. Structural requirements. Local strength. Structural failure. Vibration. Structural Steels. Mechanical behaviour. Corrosion behaviour. Failure of materials.

2. Offshore Resource Recovery

Drilling; equipment and operation. Mud gas logging. Well logging. Aspects of reservoir engineering and hydrocarbon production. Offshore engineering geology. Offshore resource recovery operations. Ocean floor mining.

DEPARTMENT OF MECHANICAL ENGINEERING
UNIVERSITY COLLEGE LONDON

M.Sc. COURSE IN OCEAN ENGINEERING

LECTURE SYLLABUS

STRUCTURES

A1 Plates and grillages (SD) 14 lectures

Plate bending
In-plane loading and elastic buckling
Stability analysis
Numerical methods for plates and grillages
Postbuckling behaviour
Yield line theory for plates

A2 Shells (WJvG)15 lectures

Stress analysis of axisymmetric shells, unstiffened and stiffened
Shell buckling
Elasto-plastic failure and design methods
Penetrations and internal structure
Composite structure

A3 Numerical methods (SD/RET) 12 lectures

Matrix displacement methods for framed structures
Finite element methods in structural mechanics
Errors convergence, modelling
Recent developments, non linearities
Substructuring for offshore structures

A4 Loading on offshore structures (MHP) 10 lectures

Drag and lift in steady motion
Wind and current loads
Wave loads on cylinders at various orientations
Drag and inertia coefficients, eddy shedding, roughness effects
Wave slam and ice loads
Wave forces on large bodies, diffraction analysis
Wave descriptions in design
Buoyancy forces

A5 Structural dynamics (RET) 15 lectures

Vibrations of continuous beams
Finite element methods in structural dynamics
Modal analysis, orthogonality, principal coordinates
Direct solution techniques in the time domain
Substructuring methods in dynamics

DYNAMICS

B1 Random process theory (RET) 10 lectures

Probability theory, distributions
Random processes, correlation, spectra
Input-output relations
FFT and simulation techniques

B2 Waves (MHP) 10 lectures

Ocean wave theories, and ranges of validity
Waves as a random process
Design spectra, long and short crested seas
Computations of spectra
Short and long term wave statistics

B3 Linear systems dynamics and control (DRB) 10 lectures

Linear second order systems
Frequency response techniques
Transient response analysis
Stability

B4 Rigid body dynamics of floating structures (MHP/ERJ) 25 lectures

Basic fluid mechanics, rotational and irrotational flow
Relationship between theory and practice
Added mass concept
Hydrostatic stability
Characteristics of floating and compliant structures
Catenary and tensioned moorings
Equations of motion for rigid body responses, and their solution
Multi-body problems, wave energy devices

B5 Hydroelasticity (RET) 5 lectures

Generalised fluid actions
Numerical methods for 3D hydrodynamics
Applications to ships and offshore structures

DESIGN

C1 Design criteria for offshore platforms (RET/MHP) 15 lecures

Offshore structures of steel and concrete in the marine environment
Reliability analysis, limit state design, Codes of Practice
Design of elements and joints
Interpretation of finite element analysis
Structure/pile interaction
Dynamics and fatigue considerations
Design of compliant systems

C2 Materials selection (WJDJ) 10 lectures

Properties of materials
Chemical principles of corrosion
Corrosion protection, sacrificial anodes, impressed current systems

C3 Fatigue and fracture (WDD) 15 lectures

Fracture mechanics and its application to fatigue
Fatigue analysis
Stress-corrosion
Non-destructive testing

C4 Foundation design (JRFA and FUGRO) 15 lectures

Basic soil mechanics
Geotechnical properties of North Sea soils
Design considerations for gravity foundations
Pile foundations, types, installation, capacity and deformation

MARITIME STUDIES

D1 Maritime Law (FJJC/NP) 10 lectures

International law of the sea
Admiralty practice
Oil pollution legislation
Marine dumping legislation
Offshore installations and Mineral Workings Acts

D2 Marine geology (EJWJ) 10 lectures

Origin and morphology of oceans and seas
Methods of geological and geophysics exploration
Ocean basins and continental shelves - exploration and exploitation
Resources of oceans and shelves

D3 Economic aspects (CR) 6 lectures

Worldwide offshore exploration and production activity
The UK offshore area: legislative background,
exploration and negotiations
Assessment of return on investments
Case study of North Sea gas development
Economics of oil refining and utilisation

ROBERT GORDON'S INSTITUTE OF TECHNOLOGY

Postgraduate Diploma in Offshore Engineering

1. Oil and Gas Production Technology

Well completion/artificial lift. Hydrocarbon processing. Separation processes. Secondary and Tertiary recovery. Platform power and service system. Production control.

2. Drilling Technology

Flow of drilling fluids. Drilling fluids and transportation of cuttings. Drilling system and equipment. Drilling techniques. Casing and cementing. Well pressure control. Offshore drilling.

3. Geology and Resrvoir Engineering

Basic geology. Petroleum geology. Reservoirs. Petroleum gasses and liquids. Reservoir fluid mechanics. Reservoir flow dynamics. Surveying and logging.

4. Planning and Control of Offshore Operations

Organisation. Law. Economics. Management. Safety. Commucation. Pipeline location and tracking.

5. Diving and Underwater Engineering

Physiological aspects of diving. Diving practice. Underwater engineering. Underwater welding and cutting. Course studies.

6. Offshore Materials Technology

Materials selection criteria. Fundamentals of marine corrosion. Conjoint corrosion phenomena. Corrosion control and measurement. Concrete in the offshore environment. Introduction to non-destructive testing. Ultrasonics and radiography.

7. Offshore Structures

Offshore installations and equipment. Hydrostatics. Waves and fluid loadings. Response of structures to slowly applied loads. Response of structures to dynamic loads. Inspection and repair. Typical course studies.

CRANFIELD INTITUTE OF TECHNOLOGY

MSc in Offshore Structures

1. Ocean Wave Dynamics

Theory of linear waves: Fluid particle velocity and acceleration, dynamic fluid pressure, wave energy. Wave forces: Drag and inertia forces on cylinders, Morison's formula, Froude-Krylov force, diffraction, fluid added mass. Wind genarated waves: Wave height spectra, spectra of wave forces and moment on cylinders, probability distributions of wave heights and forces, wave groups, mean value of maxima of random waves. Applications: Calculation of wave forces on various types of structures.

2. Materials for Offshore Structures

a. Metallurgy of steel structures

Crystal structure, imperfections, solidification, phase diagrams, solid state transformations, crystal imperfections and their effect on mechanic properties. The iron-carbon diagram, transformations, effect of cooling rate, ITT diagrams. The properties and microstructure of ferrite, austenite, pearlite, bainite, and martensite. Ductile brittle transitions, effect of processing on structure and properties. Commercially important steels and steel classifications.

b. Welding Metallurgy, Welding Technology

Effsct of environment on steel structures. Aqueous corrosion and protection; stress corrosion cracking, corrosion fatigue; influence of temperature on fracture behaviour. Evaluation of materials for offshore environments.

Inspection. Non-destructive testing and quality control. Principles of quality control NDT and DT techniques; Inspection and their relationship to design.

3. Structural Dynamics

Vibration of linear single degree of freedom system in time and frequency domains. Duhamel's integral, frequency response functions, vibration of beams, energy methods, Lagrange's equation, matrix methods, normal modes, eigenvalues, orthoganality, uncoupling of equations of motion, nonlinear systems, time step integration methods, Rayleigh-Ritz-Lagrange method for natural frequencies of beams, vibration of dtrings under tension. Application of theory to offshore structures.

4. Random vibration

a. Elementary statistics

Characteristics of random processes, probability density finctions, combined probabilities. Gaussian distribution, error function, ensemble average and square value, stationarity, ergodic hypothesis, auto and cross-correlation functions, variance and standard deviation, properties of autocorrelation function, central limit theorem, characteristics and moment generating function, binomial , Poisson, Gamma, log-normal, Weibull and Rayleigh distributions, level crossing rates of random processes.

b. General Harmonic Analysis

Parseval theorem, Fourier tranform pairs, power spectral density-autocorrelation function relations, power spectral (excitation/response) relationship, application to linear systems with one degree of freedom.

5. Structural Analysis of Stability and Finite Elements

a. Structural Stability

Stringer-skin panels, modes of buckling, other forms of construction, interaction between modes, post-buckling behaviour, imperfection sensitivity. Shear webs, incomplete diagonal-tension, corrugated webs. Buckling of beams. Exact method for local buckling, computer program for stiffened panels. Effect of yielding, residual stress due to welding, prediction of collapsed of thin-walled structures. Cylinderical shells under compression or external pressure, real behaviour of imperfect shells, effect of reinforcement. Spherical shells.

b. Finite Elements

Virtual work, strain energy, potential energy, stationary principles, Rayleigh-Ritz approximation, piecewise Rayleigh-Ritz and the finite element method, element boundary conditions, connections qualities, conformal displacement elements, direct stiffness approach, nodal forces and loads, transformation matrix, singularity of stiffness matrix, assembling global stiffness matrix, solution techniques, isoparametric elements, plate and shell elements, vibration problems, major systems, NASTRAN, PAFEC etc.

Course OM2 Design of Offshore Structures

Structural Dynamics. Single degree of freedom systems, frequency response analysis, Lagranges' equations, Hamilton's method, energy loss in dampers, natural frequencies by energy and numerical methods, elements of matrix analysis of vibration.

Random Vibration. Probabilistic concepts, Gaussian, Rayleigh binomial and Poisson distributions, root mean square value, moments of random process, average values, probability of exceedance, the Gamma distribution, average number of zero crossing, double exponential distribution, correlation functions, power spectra, stationarity, response of narrow band systems to random forces.

Ocean Wave Dynamics. Basic concepts of fluid dynamics, linear gravity wave theory, wave forces on structions, wind generated ocean waves, wave spectra, probabilistic concepts.

Theory of Structures and Strength of Materials. Principles of statics. Funicular polygon. Statically determinate structures. Method of equilibrium at the joints. Tension coefficients applied to space frames. Strain energy. Clerk Maxwell's Reciprocal Theorem. Castigliano's 1st and 2nd theorems. Application of Castigliano's 2nd Theorem to redundant structures including continuous beams, portrals and arches.

Elastic behaviour. Uniaxial stress and strain. Stress distribution with uniaxial and biaxial stress systems. Mohr's circle of stress. Principal stresses. Strain characteristics of uniaxial, biaxial and triaxial systems. Poisson's ratio. Pure shear. Modulus of rigidity. Shear forces and bending moment. Distribution of stress in a beam. Deflection of beams. Torsion of circular sections.

Course OM3 The Offshore Industry

General introduction to types of offshore structures that exist, Designing and offshore structure, Fatigue analysis of offshore structures, Safety and reliability of offshore structures, Building an offshore structure (materials, welding, NDT aspects), Pipelaying (on land and sub sea), Important material and welding consideration in the offshore and related industries, Fracture mechanics in the offshore industry.
This course will be supported by a series of colloquia at intervals throughout the year covering both materials and design subjects. The lectures will be given by outside speakers with experience of the Offshore Industry. The course is non-examinable.

Course OM4 Fracture Mechanics Fatigue and Significance of Defects

Crack initiation and propagation: stress concentration around elastic cracks, Inglis and Griffiths criteria; linear elastic fracture mechanics, plastic zones, velocity of crack propagation; fracture toughness, brittle and ductile failure. Significance of stress intensity factors (K), critical stress intensity. Geometrical effects, measurement of Kc, impact testing, crack opening displacement methods.
Influence of metallurgical variables on fracture, ductile-brittle transitions, defect types and sizes, crack tolerance. Low and high cycle fatigue phenomena, parameters affecting fatigue crack initiation and propagation, cumulative damage. Weld defects and their occurrence. Formal analysis of defects using different techniques PD6493, ASME XI, CEGB-R6.

Course OM5 Behaviour of Materials in Aggressive Environments

Aqueous and atmospheric corrosion of structural materials in marine environments. Corrosion prevention, painting, protective coatings, cathodic protection. Influence of metallurgical parameters, corrosion resistant materials. Stress corrosion cracking phenomena, influence of microstructure, stress level, surface condition. Corrosion fatigue, crack initiation and propagation. The influence of temperature on fracture processes. Erosion and related problems. Special considerations with welded structures.

Course OM6 Steel Metallurgy and Materials Selection

Heat treatment of steels, correlation of microstructure with mechanical properties. Structural steels of the BS 4360 type, ferrite pearlite steels. Pipeline steels including low carbon bainitic steels, quenched and tempered steels. Effect of composition, inclusions, grain size and production route on mechanical properties. Impact properties. weldability. Controlled rolled steels. Commercially important steels and steel classifications. Cast alloys for use in critical applications. Materials for tethers. Corrosion resistant alloys including copper and nickel base alloys: stainless steels. Concrete and reinforced concrete.

Course OM7 Welding Processes and Procedures for Fabrication and Repair

Manual metal ar welding: electrode types and characteristics. Submerged arc welding: process parameters, flux compositions. Inert gas shielded arc welding: processes, characteristics, choice of process, parameters; plasma welding. Electroslag welding: characteristics of electroslag, consumable guide and electrode gas welding, selection of consumables, welding parameters; Oxy-gas welding: process variables and application. Cutting processes: oxy-gas, arc, plasma. Fabrication techniques: selection of procedures for various materials, thickness and joint designs, pre-and post- heat, distortion, control, edge preparation, weld defects. Repair welding: materials identification, welding of rolled, forged and cast material, typical welding procedures. Underwâter welding: suitable processes, techniques and procedures.

Course OM8 Effect of Welding on Metallurgical Properties

Welding of steels: metallurgical structures and properties in the weld metal and heat affected zone; cracking problems in weld metal and heat affected zone: lamellar tearing; avoidance of defects by choice of welding procedures. Influence of welding parameters and procedures on mechanical properties; welding of specific relevant steels. Welding of non-ferrous alloys; weld defects and their avoidance; typical procedures for specific non-ferrous alloys.

Course OM9 Welding Design

The design process, loading and environment. Modes of failure. Discontinuities of the welded joint. Relation between design and experimental data. Static and dynamic behaviour of butt, fillet and spot welded joints.
Different forms of metal construction. Static and dynamic performance of plate girders, trusses and box sections. Reduction in buckling strength due to welding, residual stresses.
Use of heat treatment with reference to metallurgical and stress criteria for different modes of failure.

Course OM10 Inspection, Non-Destructive Testing and Quality Assurance

The philosophy of non-destructive testing; test techniques; ultrasonics. Radiography, electrical, magnetic, thermal and stress wave emissions, dye penetrants. Information processing and display. Particular studies related to industrial applications including underwater inspection.
Definition of quality assurance. The setting up and operation of a QA system. The application of QA in different engineering industries (e.g. power generation, construction of process plant, defence industries). Codes and specifications, their use and limitation. Statistical techniques used in QA control charts and sampling methods.

We reserve the right to amend any details of syllabus when necessary

CRANFIELD INSTITUTE OF TECHNOLOGY

MSc in Underwater Technology

Course UT1 – Project Planning and Management

Management for technologists overview: corporate planning, finance and accounting, legal responsibilities, industrial relations and organisation behaviour, business policy, industrial marketing, management for design, management of complex technological projects of substantial cost and value, business game.
Management of complex technological projects: project finance and appraisal; raising capital, feasibility and appraisal studies, insurance and bonding, exchange risks, choice of client, project strategy. Capital cost estimating and tendering: appraisal of suppliers and subcontractors, the use of computers in design and estimating.

Course UT2 – Underwater Tasks and Delivery System

Tasks: underwater inspection, legislation, codes of practice, inspection procedures, inspection and NDT techniques, cleaning, monitoring, data collection, transmission and storage. Techniques for crack monitoring, corrosion monitoring, cathodic protection monitoring, underwater repairs, welding in the wet, use of habitats, friction welding, explosive welding, effects of moisture and pressure on weld quality and performance, grouting techniques and adhesives for steel and concrete structures.
Underwater tools for repair, maintenance and replacement of parts: refurbishment of equipment, corrosion prevention coatings and cathodic protection systems, bolting, bolt tensioning, pipeline stabilization techniques. Use of explosives: lifting and moving objects underwater.
Delivery systems: normal and saturation diving, physiological and human factors, diving equipment and support facilities. Submersibles: one atmosphere diving suits. Remotely operated vehicles: manned and unmanned techniques.

Course UT3 – Underwater Instrumentation

Basic physical principles of sensors and communication processes. Techniques for monitoring submersibles and diver activities and performance. Underwater cameras and video systems, photography and photogrammetry. Sonar: surveillance and monitoring systems, positioning and control of vehicles, marinisation of underwater instrumentation, electrical safety standards for subsea use. Underwater lighting, hydraulics. Communication systems: sonar, cables, optical fibres. Underwater surveying and navigation.
Computer technology: system architecture for mainframes and microcomputers, operating systems, language level, machine code to high level. Advantages and disadvantages of various languages and their relation to user applications. Structured programming: basic constructs, examples of languages, instrumentation, data acquisition, signal conditioning, analogue to digital converters and digital to analogue converters.

Course UT4 – Offshore Structures and Materials Performance

Description of ocean structures: fixed structures, jacket and concrete structures, floating structures, subsea completion systems, pipelines, dredgers, underwater mining equipment. Vessels and platforms for subsea operations. Sea keeping capabilities.
Design concepts: hydrostatic and hydrodynamic stability. Foundation analysis, construction and installation constraints, design rules, codes of practice. Materials performance: effects of the environment on degradation and failure of materials, fouling, corrosion, corrosion fatigue, fracture, buckling, basic metallurgy, welding. Sea water chemistry and biology, marine growth on structures, air-sea interactions, wave statistics and spectra, sea states, ocean currents, seabed topography, soil characteristics, wave induced forces, underwater visibility

Course UT5 – Safety Risk and Reliability

Risk analysis, construction and evaluation of fault trees and event trees. Structural reliability, probabilistic techniques, safety factors, quality control, human factors. Reliability of inspection and underwater tasks, safety of divers, weather down-time predictions

MSc in Offshore Engineering

1. MARINE STRUCTURES

1.1 Structural Response Analysis

Elastic analysis of finite element methods: Introduction to matrix structural analysis. Development of finite element methods. Element stiffness formulations in one or two dimensions. Further element assembly and solution techniques. Practical aspects of finite element methods. Application to plates and shells.

The analysis of structural failure: Definition of structural failure. Significant of practical impections. Concepts and laws of plasticity. Plastic theory of structures. Yeild line theory. Membrane stresses and their effects. Buckling of columns, plates, panels and grillages. Brittle fracture. Fracture mechanics and its applications. Fatigue.

Coursework: Students will have a choice of projects related to the above subjects.

1.2 Sructural Design Synthesis

Philosophy and Procedure of Design: Historical development of structural design methods. Shortcomings of the traditional methods. Progress towards rational design procedure.

Load Actions of Marine Structures: Origin and classification of load actions. Empirical and statistical methods to load determination: derivation of design values.

Structural Design Criteria and Reliability Assessment: Damage and collapse modes of marine structures. Need for safety margins. Methods of defining and evaluating safety margins. Use of load factors. Effect of production processes. Introduction to the statistical assessment of reliability.

Analysis of Structural Response: Brief review of the pricipal tools of structural analysis for marine structures.

Structural Optimization: The general optimization procedure. The objective function. The constraints. Analytic methods. Application to simple examples of basic elements of marine structures.

Structural Design for Production: Interactions of design production. Methods of reducing costs of fabrication; standardization of parts, connections. Effects of construction processes on structural strength stiffness and stability.

2. OFFSHORE ENGINEERING

2.1 Structures and Vehicles Offshore

Ocean Resources: Exploration and exploitation. Geology of the seabed. Specifications of offshore vehicles and structures. Stability of unusual marine structures. Working underwater. Design for operation in ice infested waters. International law of the sea.

2.2 Offshore Engineering Applications

Lectures, seminars and case studies, which may be taken from the following non-exhaustive list:

Ballasting requirements for load-outs in tidal conditions, characteristic of catenary moorings. Towing and towline dynamics in a seaway. Estimation of crane-barge motions and calculations of weather windows. Simulation of a single point mooring. Behaviour of flexible risers. Dynamics of the ROV including the effect of the umbilical.

Assessment will be in-course by means of design study reports.

3. FLUID-STRUCTURE INTERACTIONS

The Wave Environment: Deterministic wave theory. Stochasti representation of sea-states. Spectral analysis and sea-spectra. Simulation of random seas.

Wave Induced Loads: The calculations of wave wave induced loads using inviscid theory and by emphirical and semi-emphirical methods.

Marine Dynamics: Equations of motion. Dynamic loading. Vortex shedding and damping mechanisms. Frequency domain and time domain models.

Case Studies: The practical application of the above concepts.

APPENDIX B

Results of Linear Wave Theory

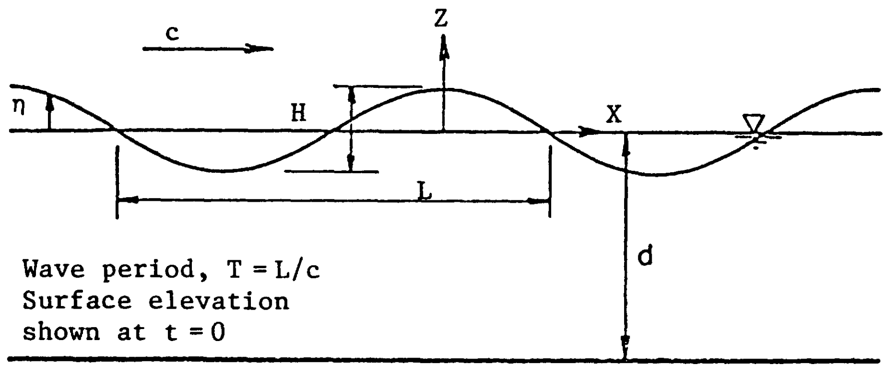


Fig.49 : Definition sketch for a progressive wave train

Velocity potential	$\phi = \frac{\pi H}{kT}\frac{\cosh(ks)}{\sinh(kd)}\sin\theta$
	$= \frac{gH}{2\omega}\frac{\cosh(ks)}{\cosh(kd)}\sin\theta$
Dispersion relation	$c^2 = \frac{\omega^2}{k^2} = \frac{g}{k}\tanh(kd)$
Surface elevation	$\eta = \frac{H}{2}\cos\theta$
Horizontal particle displacement	$\xi = -\frac{H}{2}\frac{\cosh(ks)}{\sinh(kd)}\sin\theta$
Vertical particle displacement	$\zeta = \frac{H}{2}\frac{\sinh(ks)}{\sinh(kd)}\cos\theta$
Horizontal particle velocity	$u = \frac{\pi H}{T}\frac{\cosh(ks)}{\sinh(kd)}\cos\theta$
Vertical particle velocity	$w = \frac{\pi H}{T}\frac{\sinh(ks)}{\sinh(kd)}\sin\theta$
Horizontal particle acceleration	$\frac{\partial u}{\partial t} = \frac{2\pi^2 H}{T^2}\frac{\cosh(ks)}{\sinh(kd)}\sin\theta$
Vertical particle acceleration	$\frac{\partial w}{\partial t} = -\frac{2\pi^2 H}{T^2}\frac{\sinh(ks)}{\sinh(kd)}\cos\theta$
Pressure	$p = -\rho g z + \frac{1}{2}\rho g H\frac{\cosh(ks)}{\cosh(kd)}\cos\theta$
Group velocity	$c_G = \frac{1}{2}\left[1 + \frac{2kd}{\sinh(2kd)}\right]c$
Average energy density	$E = \frac{1}{8}\rho g H^2$
Energy flux	$P = E c_G$
Radiation stress	$S_{xx} = \left[\frac{1}{2} + \frac{2kd}{\sinh(2kd)}\right]E$
	$S_{xy} = S_{yx} = 0$
	$S_{yy} = \left[\frac{kd}{\sinh(2kd)}\right]E$

	Shallow Water	Deep Water
Range of validity	$kd < \frac{\pi}{10}$	$kd > \pi$
	$\frac{d}{L} < \frac{1}{20}$	$\frac{d}{L} > \frac{1}{2}$
	$\frac{d}{gT^2} < 0.0025$	$\frac{d}{gT^2} > 0.08$
Velocity potential	$\phi = \frac{\pi H}{k^2 Td} \sin\theta$	$\phi = \frac{\pi H}{kT} e^{kz} \sin\theta$
	$= \frac{gH}{2\omega} \sin\theta$	$= \frac{gH}{2\omega} e^{kz} \sin\theta$
Dispersion relation	$c^2 = \frac{\omega^2}{k^2} = gd$	$c^2 = c_0^2 = \frac{\omega^2}{k^2} = \frac{g}{k}$
Wave length	$L = T\sqrt{gd}$	$L = L_0 = gT^2/2\pi$
Surface elevation	$\eta = \frac{H}{2}\cos\theta$	$\eta = \frac{H}{2}\cos\theta$
Horizontal particle displacement	$\xi = -\frac{H}{2kd}\sin\theta$	$\xi = -\frac{H}{2} e^{kz}\sin\theta$
Vertical particle displacement	$\zeta = \frac{H}{2}\left(1 + \frac{z}{d}\right)\cos\theta$	$\zeta = \frac{H}{2} e^{kz}\cos\theta$
Horizontal particle velocity	$u = \frac{\pi H}{T(kd)}\cos\theta$	$u = \frac{\pi H}{T} e^{kz}\cos\theta$
Vertical particle velocity	$w = \frac{\pi H}{T}\left(1 + \frac{z}{d}\right)\sin\theta$	$w = \frac{\pi H}{T} e^{kz}\sin\theta$
Horizontal particle acceleration	$\frac{\partial u}{\partial t} = \frac{2\pi^2 H}{T^2(kd)}\sin\theta$	$\frac{\partial u}{\partial t} = \frac{2\pi^2 H}{T^2} e^{kz}\sin\theta$
Vertical particle acceleration	$\frac{\partial w}{\partial t} = -\frac{2\pi^2 H}{T^2}\left(1 + \frac{z}{d}\right)\cos\theta$	$\frac{\partial w}{\partial t} = -\frac{2\pi^2 H}{T^2} e^{kz}\cos\theta$
Pressure	$p = -\rho gz + \frac{1}{2}\rho gH\cos\theta$	$p = -\rho gz + \frac{1}{2}\rho gH e^{kz}\cos\theta$
Group velocity	$c_G = c$	$c_G = \frac{1}{2}c$
Average energy density	$E = \frac{1}{8}\rho gH^2$	$E = \frac{1}{8}\rho gH^2$
Energy flux	$P = Ec$	$P = \frac{1}{2}Ec$
Radiation stress	$S_{xx} = \frac{3}{2}E$	$S_{xx} = \frac{1}{2}E$
	$S_{xy} = S_{yx} = 0$	$S_{xy} = S_{yx} = 0$
	$S_{yy} = \frac{1}{2}E$	$S_{yy} = 0$

APPENDIX C

Output of Hydrodynamic Computer Program

STRUCTURE Jacket2.dat

DRAFT 80.000 (M)   ANGLE OF ORIENTATION   0.000 (DEGREES)

WAVE LENGTH 192.754 (M)   WAVE FREQUENCY   0.090 (HZ)   WAVE AMPLITUDE   3.500 (M)

==

SUMMARY OF DATA FOR STRUCTURE : Jacket2.dat

MEMBER DATA

MEMBER NUMBER	START JOINT	END JOINT	NO OF JOINTS	RADIUS	LENGTH
1	1	3	3	1.000	85.000
2	4	6	3	1.000	85.000
3	7	9	3	1.000	85.000
4	10	12	3	1.000	85.000
5	2	5	2	0.750	55.000
6	5	8	2	0.750	55.000
7	8	11	2	0.750	55.000
8	11	2	2	0.750	55.000
9	3	6	2	0.750	55.000
10	6	9	2	0.750	55.000
11	9	12	2	0.750	55.000
12	12	3	2	0.750	55.000
13	1	5	2	0.500	69.507
14	4	8	2	0.500	69.507
15	10	8	2	0.500	69.507
16	1	11	2	0.500	69.507
17	2	6	2	0.500	69.507
18	5	9	2	0.500	69.507
19	11	9	2	0.500	69.507
20	2	12	2	0.500	69.507

JOINT DATA

JOINT NUMBER	X,Y,Z COORDINATES	CONTINUOUS MEMBER	INTERCOSTAL MEMBERS	MEMBERS REQUIRING END CORRECTIONS
1	-27.500, 0.000, -27.500	-	1 13 16	13 16
2	-27.500, 42.500, -27.500	1	5 8 17 20	5 8 17 20
3	-27.500, 85.000, -27.500	-	1 9 12	9 12
4	27.500, 0.000, -27.500	-	2 14	14
5	27.500, 42.500, -27.500	2	5 6 13 18	5 6 13 18
6	27.500, 85.000, -27.500	-	2 9 10 17	9 10 17
7	27.500, 0.000, 27.500	-	3	-
8	27.500, 42.500, 27.500	3	6 7 14 15	6 7 14 15
9	27.500, 85.000, 27.500	-	3 10 11 18 19	10 11 18 19
10	-27.500, 0.000, 27.500	-	4 15	15
11	-27.500, 42.500, 27.500	4	7 8 16 19	7 8 16 19
12	-27.500, 85.000, 27.500	-	4 11 12 20	11 12 20

TRANSFORMATION MATRICES FOR EACH MEMBER

```
MEMBER NO  1
| X |   |  0.00  0.00  1.00 | | U |
| Y | = |  1.00  0.00  0.00 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO  2
| X |   |  0.00  0.00  1.00 | | U |
| Y | = |  1.00  0.00  0.00 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO  3
| X |   |  0.00  0.00  1.00 | | U |
| Y | = |  1.00  0.00  0.00 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO  4
| X |   |  0.00  0.00  1.00 | | U |
| Y | = |  1.00  0.00  0.00 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO  5
| X |   |  1.00  0.00  0.00 | | U |
| Y | = |  0.00  0.00 -1.00 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO  6
| X |   |  0.00  1.00  0.00 | | U |
| Y | = |  0.00  0.00  1.00 | | V |
| Z |   |  1.00  0.00  0.00 | | W |

MEMBER NO  7
| X |   | -1.00  0.00  0.00 | | U |
| Y | = |  0.00  0.00  1.00 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO  8
| X |   |  0.00  1.00  0.00 | | U |
| Y | = |  0.00  0.00 -1.00 | | V |
| Z |   | -1.00  0.00  0.00 | | W |

MEMBER NO  9
| X |   |  1.00  0.00  0.00 | | U |
| Y | = |  0.00  0.00 -1.00 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO 10
| X |   |  0.00  1.00  0.00 | | U |
| Y | = |  0.00  0.00  1.00 | | V |
| Z |   |  1.00  0.00  0.00 | | W |

MEMBER NO 11
| X |   | -1.00  0.00  0.00 | | U |
| Y | = |  0.00  0.00  1.00 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO 12
| X |   |  0.00  1.00  0.00 | | U |
| Y | = |  0.00  0.00 -1.00 | | V |
| Z |   | -1.00  0.00  0.00 | | W |

MEMBER NO 13
| X |   |  0.79  0.00  0.61 | | U |
| Y | = |  0.61  0.00 -0.79 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO 14
| X |   |  0.00  1.00  0.00 | | U |
| Y | = |  0.61  0.00  0.79 | | V |
| Z |   |  0.79  0.00 -0.61 | | W |

MEMBER NO 15
| X |   |  0.79  0.00  0.61 | | U |
| Y | = |  0.61  0.00 -0.79 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO 16
| X |   |  0.00  1.00  0.00 | | U |
| Y | = |  0.61  0.00  0.79 | | V |
| Z |   |  0.79  0.00 -0.61 | | W |

MEMBER NO 17
| X |   |  0.79  0.00  0.61 | | U |
| Y | = |  0.61  0.00 -0.79 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO 18
| X |   |  0.00  1.00  0.00 | | U |
| Y | = |  0.61  0.00  0.79 | | V |
| Z |   |  0.79  0.00 -0.61 | | W |

MEMBER NO 19
| X |   |  0.79  0.00  0.61 | | U |
| Y | = |  0.61  0.00 -0.79 | | V |
| Z |   |  0.00  1.00  0.00 | | W |

MEMBER NO 20
| X |   |  0.00  1.00  0.00 | | U |
| Y | = |  0.61  0.00  0.79 | | V |
| Z |   |  0.79  0.00 -0.61 | | W |
```

MEMBER LOAD DISTRIBUTIONS

T1/T= 0.00

MEMBER NO 1

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	-0.410
2	10.000	0.000	-0.565
3	20.000	0.000	-0.778
4	30.000	0.000	-1.067
5	40.000	0.000	-1.459
6	50.000	0.000	-1.985
7	60.000	0.000	-2.678
8	70.000	0.000	-3.575
9	80.000	0.000	-4.691
TOTAL MEMBER FORCE:		0.000	-145.657
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	-7976.657

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
2	5	41.750	43.250	0.000	8.028
2	8	41.750	43.250	7.625	0.000
2	17	42.641	43.905	0.000	3.432
2	20	42.641	43.905	3.278	0.000
TOTAL MEMBER COR. FORCE:				15.580	16.379
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				665.352	699.456

MEMBER NO 2

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	0.420
2	10.000	0.000	0.585
3	20.000	0.000	0.815
4	30.000	0.000	1.139
5	40.000	0.000	1.598
6	50.000	0.000	2.250
7	60.000	0.000	3.188
8	70.000	0.000	4.553
9	80.000	0.000	6.569
TOTAL MEMBER FORCE:		0.000	174.344
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	9845.730

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
5	5	41.750	43.250	0.000	-8.028
5	6	41.750	43.250	7.625	0.000
5	13	41.095	42.359	0.000	-3.236
5	18	42.641	43.905	3.278	0.000
TOTAL MEMBER COR. FORCE:				15.580	-16.131
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				665.352	-682.423

MEMBER NO 3

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	0.420
2	10.000	0.000	0.585
3	20.000	0.000	0.815
4	30.000	0.000	1.139
5	40.000	0.000	1.598
6	50.000	0.000	2.250
7	60.000	0.000	3.188
8	70.000	0.000	4.553
9	80.000	0.000	6.569
TOTAL MEMBER FORCE:		0.000	174.344
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	9845.730

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
8	6	41.750	43.250	-7.625	0.000
8	7	41.750	43.250	0.000	-8.028
8	14	41.095	42.359	-3.091	0.000
8	15	41.095	42.359	0.000	-3.236
TOTAL MEMBER COR. FORCE:				-15.343	-16.131
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				-649.074	-682.423

MEMBER NO 4

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	-0.410
2	10.000	0.000	-0.565
3	20.000	0.000	-0.778
4	30.000	0.000	-1.067
5	40.000	0.000	-1.459
6	50.000	0.000	-1.985
7	60.000	0.000	-2.678
8	70.000	0.000	-3.575
9	80.000	0.000	-4.691
TOTAL MEMBER FORCE:		0.000	-145.657
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	-7976.657

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
11	7	41.750	43.250	0.000	8.028
11	8	41.750	43.250	-7.625	0.000
11	16	41.095	42.359	-3.091	0.000
11	19	42.641	43.905	0.000	3.432
TOTAL MEMBER COR. FORCE:				-15.343	16.379
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				-649.074	699.456

MEMBER NO 5

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.000	0.000	0.866
2	9.833	0.000	1.048
3	18.667	0.000	1.158
4	27.500	0.000	1.194
5	36.333	0.000	1.132
6	45.167	0.000	0.955
7	54.000	0.000	0.685
TOTAL MEMBER FORCE:		0.000	55.710
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	1497.240

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 6

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.000	0.994	-0.650
2	9.833	0.994	-0.650
3	18.667	0.994	-0.650
4	27.500	0.994	-0.650
5	36.333	0.994	-0.650
6	45.167	0.994	-0.650
7	54.000	0.994	-0.650
TOTAL MEMBER FORCE:		52.675	-34.452
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		1448.558	-947.422

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 7

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.000	0.000	-0.685
2	9.833	0.000	-0.955
3	18.667	0.000	-1.132
4	27.500	0.000	-1.194
5	36.333	0.000	-1.158
6	45.167	0.000	-1.048
7	54.000	0.000	-0.866
TOTAL MEMBER FORCE:		0.000	-55.710
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	-1566.836

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 8

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.000	-0.872	0.841
2	9.833	-0.872	0.841
3	18.667	-0.872	0.841
4	27.500	-0.872	0.841
5	36.333	-0.872	0.841
6	45.167	-0.872	0.841
7	54.000	-0.872	0.841
TOTAL MEMBER FORCE:		-46.197	44.588
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		-1270.420	1226.171

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 13

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	0.009
2	11.374	0.000	0.060
3	22.748	0.000	0.130
4	34.122	0.000	0.215
5	45.496	0.000	0.311
6	56.870	0.000	0.411
7	68.243	0.000	0.502
TOTAL MEMBER FORCE:		0.000	15.686
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	735.950

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

AXIAL FORCE AT END 1 (U DIRECTION) 1.258(KN)

MEMBER NO 14

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.106	-0.063
2	11.374	0.134	-0.078
3	22.748	0.170	-0.097
4	34.122	0.215	-0.120
5	45.496	0.273	-0.147
6	56.870	0.347	-0.180
7	68.243	0.443	-0.218
TOTAL MEMBER FORCE:		15.986	-8.648
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		671.277	-354.366

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

AXIAL FORCE AT END 1 (U DIRECTION) 1.267(KN)

MEMBER NO 15

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	0.009
2	11.374	0.000	0.060
3	22.748	0.000	0.130
4	34.122	0.000	0.215
5	45.496	0.000	0.311
6	56.870	0.000	0.411
7	68.243	0.000	0.502
TOTAL MEMBER FORCE:		0.000	15.686
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	735.950

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

AXIAL FORCE AT END 1 (U DIRECTION) 1.258(KN)

MEMBER NO 16

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	-0.101	-0.068
2	11.374	-0.126	-0.086
3	22.748	-0.157	-0.109
4	34.122	-0.195	-0.139
5	45.496	-0.241	-0.178
6	56.870	-0.298	-0.228
7	68.243	-0.366	-0.294
TOTAL MEMBER FORCE:		-14.170	-10.427
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		-584.123	-439.756

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

AXIAL FORCE AT END 1 (U DIRECTION) 1.267(KN)

MEMBER NO 17

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.264	0.000	0.136
2	11.275	0.000	0.350
3	21.286	0.000	0.609
4	31.297	0.000	0.895
5	41.308	0.000	1.187
6	51.319	0.000	1.479
7	61.330	0.000	1.800
TOTAL MEMBER FORCE:		0.000	54.802
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	2222.380

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 18

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.264	0.468	-0.227
2	11.275	0.583	-0.266
3	21.286	0.729	-0.308
4	31.297	0.915	-0.350
5	41.308	1.156	-0.390
6	51.319	1.468	-0.421
7	61.330	1.877	-0.430
TOTAL MEMBER FORCE:		59.998	-20.687
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		2284.076	-714.719

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 19

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.264	0.000	0.136
2	11.275	0.000	0.350
3	21.286	0.000	0.609
4	31.297	0.000	0.895
5	41.308	0.000	1.187
6	51.319	0.000	1.479
7	61.330	0.000	1.800
TOTAL MEMBER FORCE:		0.000	54.802
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	2222.380

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 20

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.264	-0.382	-0.311
2	11.275	-0.455	-0.391
3	21.286	-0.538	-0.494
4	31.297	-0.632	-0.628
5	41.308	-0.733	-0.805
6	51.319	-0.838	-1.038
7	61.330	-0.938	-1.350
TOTAL MEMBER FORCE:		-38.581	-41.671
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		-1378.420	-1602.048

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER.COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

```
SUMMARY OF TOTAL FORCES AND MOMENTS ON THE STRUCTURE
----------------------------------------------------
(MOMENTS ABOUT ORIGIN OF THE STRUCTURE REF. SYSTEM)          (T1/T= 0.00)

     TOTAL SURGE FORCE=      175.769  (KN)
     TOTAL HEAVE FORCE=     -363.363  (KN)
     TOTAL SWAY FORCE =       52.270  (KN)
     TOTAL ROLL MOMENT=     3034.500  (KN.M)
      TOTAL YAW MOMENT=      529.443  (KN.M)
    TOTAL PITCH MOMENT=   -10460.607  (KN.M)
```

MEMBER LOAD DISTRIBUTIONS

T1/T= 0.25

MEMBER NO 1

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	-0.340
2	10.000	0.000	-0.475
3	20.000	0.000	-0.666
4	30.000	0.000	-0.938
5	40.000	0.000	-1.330
6	50.000	0.000	-1.901
7	60.000	0.000	-2.744
8	70.000	0.000	-4.015
9	80.000	0.000	-5.971
TOTAL MEMBER FORCE:		0.000	-150.351
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	-8586.103

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
2	5	41.750	43.250	0.000	-9.202
2	8	41.750	43.250	-9.538	0.000
2	17	42.641	43.905	0.000	-3.973
2	20	42.641	43.905	-4.100	0.000
TOTAL MEMBER COR. FORCE:				-19.489	-18.824
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				-832.298	-803.908

MEMBER NO 2

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	-0.324
2	10.000	0.000	-0.444
3	20.000	0.000	-0.607
4	30.000	0.000	-0.826
5	40.000	0.000	-1.114
6	50.000	0.000	-1.485
7	60.000	0.000	-1.946
8	70.000	0.000	-2.483
9	80.000	0.000	-3.031
TOTAL MEMBER FORCE:		0.000	-105.462
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	-5661.377

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
5	5	41.750	43.250	0.000	-9.202
5	6	41.750	43.250	9.538	0.000
5	13	41.095	42.359	0.000	-3.746
5	18	42.641	43.905	4.100	0.000
TOTAL MEMBER COR. FORCE:				19.489	-18.537
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				832.300	-784.173

MEMBER NO 3

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	-0.324
2	10.000	0.000	-0.444
3	20.000	0.000	-0.607
4	30.000	0.000	-0.826
5	40.000	0.000	-1.114
6	50.000	0.000	-1.485
7	60.000	0.000	-1.946
8	70.000	0.000	-2.483
9	80.000	0.000	-3.031
TOTAL MEMBER FORCE:		0.000	-105.462
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	-5661.377

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
8	6	41.750	43.250	-9.538	0.000
8	7	41.750	43.250	0.000	-9.202
8	14	41.095	42.359	-3.866	0.000
8	15	41.095	42.359	0.000	-3.746
TOTAL MEMBER COR. FORCE:				-19.193	-18.537
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				-811.937	-784.173

MEMBER NO 4

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	-0.340
2	10.000	0.000	-0.475
3	20.000	0.000	-0.666
4	30.000	0.000	-0.938
5	40.000	0.000	-1.330
6	50.000	0.000	-1.901
7	60.000	0.000	-2.744
8	70.000	0.000	-4.015
9	80.000	0.000	-5.971
TOTAL MEMBER FORCE:		0.000	-150.351
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	-8586.103

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
11	7	41.750	43.250	0.000	-9.202
11	8	41.750	43.250	9.538	0.000
11	16	41.095	42.359	3.866	0.000
11	19	42.641	43.905	0.000	-3.973
TOTAL MEMBER COR. FORCE:				19.193	-18.824
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				811.935	-803.908

MEMBER NO 5

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.000	0.000	-0.842
2	9.833	0.000	-0.540
3	18.667	0.000	-0.195
4	27.500	0.000	0.157
5	36.333	0.000	0.483
6	45.167	0.000	0.761
7	54.000	0.000	0.974
TOTAL MEMBER FORCE:		0.000	6.530
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	627.165

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 6

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.000	-0.650	-0.994
2	9.833	-0.650	-0.994
3	18.667	-0.650	-0.994
4	27.500	-0.650	-0.994
5	36.333	-0.650	-0.994
6	45.167	-0.650	-0.994
7	54.000	-0.650	-0.994
TOTAL MEMBER FORCE:		-34.452	-52.675
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		-947.420	-1448.560

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 15

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	-0.133
2	11.374	0.000	-0.158
3	22.748	0.000	-0.167
4	34.122	0.000	-0.148
5	45.496	0.000	-0.088
6	56.870	0.000	0.027
7	68.243	0.000	0.201
TOTAL MEMBER FORCE:		0.000	-5.905
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	-87.891

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

AXIAL FORCE AT END 1 (U DIRECTION) -1.591(KN)

MEMBER NO 14

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	-0.079	-0.084
2	11.374	-0.098	-0.105
3	22.748	-0.121	-0.133
4	34.122	-0.148	-0.168
5	45.496	-0.181	-0.213
6	56.870	-0.219	-0.270
7	68.243	-0.263	-0.344
TOTAL MEMBER FORCE:		-10.632	-12.499
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		-433.603	-523.975

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

AXIAL FORCE AT END 1 (U DIRECTION) 1.584(KN)

MEMBER NO 13

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	0.000	-0.133
2	11.374	0.000	-0.158
3	22.748	0.000	-0.167
4	34.122	0.000	-0.148
5	45.496	0.000	-0.088
6	56.870	0.000	0.027
7	68.243	0.000	0.201
TOTAL MEMBER FORCE:		0.000	-5.905
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	-87.891

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

AXIAL FORCE AT END 1 (U DIRECTION) -1.591(KN)

MEMBER NO 8

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.000	-0.841	-0.872
2	9.833	-0.841	-0.872
3	18.667	-0.841	-0.872
4	27.500	-0.841	-0.872
5	36.333	-0.841	-0.872
6	45.167	-0.841	-0.872
7	54.000	-0.841	-0.872
TOTAL MEMBER FORCE:		-44.588	-46.197
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		-1226.172	-1270.418

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 7

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.000	0.000	-0.974
2	9.833	0.000	-0.761
3	18.667	0.000	-0.483
4	27.500	0.000	-0.157
5	36.333	0.000	0.195
6	45.167	0.000	0.540
7	54.000	0.000	0.842
TOTAL MEMBER FORCE:		0.000	-6.530
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	268.028

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 16

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	0.000	-0.087	0.080
2	11.374	-0.110	0.100
3	22.748	-0.140	0.125
4	34.122	-0.179	0.156
5	45.496	-0.230	0.193
6	56.870	-0.296	0.240
7	68.243	-0.384	0.296
TOTAL MEMBER FORCE:		-13.474	11.362
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		-569.982	469.404

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

AXIAL FORCE AT END 1 (U DIRECTION) -1.584(KN)

MEMBER NO 17

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.264	0.000	-0.543
2	11.275	0.000	-0.618
3	21.286	0.000	-0.615
4	31.297	0.000	-0.477
5	41.308	0.000	-0.145
6	51.319	0.000	0.429
7	61.330	0.000	1.253
TOTAL MEMBER FORCE:		0.000	-11.603
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	128.104

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 18

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.264	-0.273	-0.363
2	11.275	-0.315	-0.451
3	21.286	-0.358	-0.561
4	31.297	-0.396	-0.701
5	41.308	-0.424	-0.880
6	51.319	-0.429	-1.110
7	61.330	-0.390	-1.408
TOTAL MEMBER FORCE:		-22.647	-45.707
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		-755.344	-1732.570

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 19

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.264	0.000	-0.543
2	11.275	0.000	-0.618
3	21.286	0.000	-0.615
4	31.297	0.000	-0.477
5	41.308	0.000	-0.145
6	51.319	0.000	0.429
7	61.330	0.000	1.253
TOTAL MEMBER FORCE:		0.000	-11.603
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		0.000	128.104

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

MEMBER NO 20

DISTRIBUTION OF LATERAL LOADS ALONG THE U AXIS

NODE NO	AXIAL DISTANCE FROM FIRST JOINT ON MEMBER (METRES)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
1	1.264	-0.407	0.310
2	11.275	-0.515	0.371
3	21.286	-0.655	0.442
4	31.297	-0.840	0.523
5	41.308	-1.086	0.615
6	51.319	-1.415	0.715
7	61.330	-1.860	0.820
TOTAL MEMBER FORCE:		-56.159	32.297
TOTAL MEMBER MOMENT: (ABOUT FIRST JOINT ON MEMBER)		-2172.508	1165.506

CORRECTIONS FOR INTERSECTING MEMBERS

JOINT NO	INTERSECTING MEMBER	AXIAL DIST FROM START PT OF MEMBER TO START PT OF LOADING (M)	END PT OF LOADING (M)	V DIRECTION LOAD (KN/M)	W DIRECTION LOAD (KN/M)
TOTAL MEMBER COR. FORCE:				0.000	0.000
TOTAL MEMBER COR. MOMENT: (ABOUT FIRST JOINT OF MEMBER)				0.000	0.000

```
SUMMARY OF TOTAL FORCES AND MOMENTS ON THE STRUCTURE
----------------------------------------------------
(MOMENTS ABOUT ORIGIN OF THE STRUCTURE REF. SYSTEM)          (T1/T= 0.25)

     TOTAL SURGE FORCE=    -792.231  (KN)
     TOTAL HEAVE FORCE=      -5.286  (KN)
     TOTAL SWAY FORCE =       8.895  (KN)
     TOTAL ROLL MOMENT=     653.563  (KN.M)
      TOTAL YAW MOMENT=   -2078.892  (KN.M)
    TOTAL PITCH MOMENT=   34820.074  (KN.M)

SUMMARY OF MAXIMUM FORCES AND MOMENTS ON THE STRUCTURE
------------------------------------------------------

     MAX. SURGE FORCE=     811.495  (KN)
     MAX. HEAVE FORCE=     363.401  (KN)
     MAX. SWAY FORCE =      53.021  (KN)
     MAX. ROLL MOMENT=    3104.083  (KN.M)
      MAX. YAW MOMENT=    2145.251  (KN.M)
    MAX. PITCH MOMENT=   36357.418  (KN.M)
```

APPENDIX D

Output of Frame Analysis Computer Program

RIGID JOINTED PLANE FRAMEWORK ANALYSIS

DATA SUPPLIED

NUMBER OF JOINTS	38
NUMBER OF MEMBERS	40
NUMBER OF JOINT RESTRAINTS	4
NUMBER OF JOINT FORCES	12
NUMBER OF INTERMIDIATE FORCES	50

JOINT COORDINATES

JOINT	X(M)	Y(M)
1	0.000	0.000
2	0.000	10.000
3	0.000	20.000
4	0.000	30.000
5	0.000	40.000
6	0.000	42.500
7	0.000	50.000
8	0.000	60.000
9	0.000	70.000
10	0.000	80.000
11	0.000	85.000
12	55.000	0.000
13	55.000	10.000
14	55.000	20.000
15	55.000	30.000
16	55.000	40.000
17	55.000	42.500
18	55.000	50.000
19	55.000	60.000
20	55.000	70.000
21	55.000	80.000
22	55.000	85.000
23	9.000	7.000
24	18.000	14.000
25	27.000	21.000
26	36.000	28.000
27	45.000	35.000
28	45.200	42.500
29	36.300	42.500
30	27.500	42.500
31	18.700	42.500
32	9.800	42.500
33	9.000	50.000
34	17.000	56.000
35	25.000	62.000
36	33.000	68.000
37	41.000	74.000
38	49.000	80.000

MEMBER CONNECTIVITY

MEMBER	JOINT 1	JOINT 2
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	6	7
7	7	8
8	8	9
9	9	10
10	10	11
11	12	13
12	13	14
13	14	15
14	15	16
15	16	17
16	17	18
17	18	19
18	19	20
19	20	21
20	21	22
21	1	23
22	23	24
23	24	25
24	25	26
25	26	27
26	17	27
27	27	28
28	28	29
29	29	30
30	30	31
31	31	32
32	6	32
33	6	33
34	33	34
35	34	35
36	35	36
37	36	37
38	37	38
39	22	38
40	11	22

MEMBER PROPERTIES

MEMBER	E(N/M2)	AREA(M2)	I(M4)
1	0.210E+12	0.155E+00	0.756E-01
2	0.210E+12	0.155E+00	0.756E-01
3	0.210E+12	0.155E+00	0.756E-01
4	0.210E+12	0.155E+00	0.756E-01
5	0.210E+12	0.155E+00	0.756E-01
6	0.210E+12	0.155E+00	0.756E-01
7	0.210E+12	0.155E+00	0.756E-01
8	0.210E+12	0.155E+00	0.756E-01
9	0.210E+12	0.155E+00	0.756E-01
10	0.210E+12	0.155E+00	0.756E-01
11	0.210E+12	0.155E+00	0.756E-01
12	0.210E+12	0.155E+00	0.756E-01
13	0.210E+12	0.155E+00	0.756E-01
14	0.210E+12	0.155E+00	0.756E-01
15	0.210E+12	0.155E+00	0.756E-01
16	0.210E+12	0.155E+00	0.756E-01
17	0.210E+12	0.155E+00	0.756E-01
18	0.210E+12	0.155E+00	0.756E-01
19	0.210E+12	0.155E+00	0.756E-01
20	0.210E+12	0.155E+00	0.756E-01
21	0.210E+12	0.464E-01	0.563E-02
22	0.210E+12	0.464E-01	0.563E-02
23	0.210E+12	0.464E-01	0.563E-02
24	0.210E+12	0.464E-01	0.563E-02
25	0.210E+12	0.464E-01	0.563E-02
26	0.210E+12	0.464E-01	0.563E-02
27	0.210E+12	0.930E-01	0.255E-01
28	0.210E+12	0.930E-01	0.255E-01
29	0.210E+12	0.930E-01	0.255E-01
30	0.210E+12	0.930E-01	0.255E-01
31	0.210E+12	0.930E-01	0.255E-01
32	0.210E+12	0.930E-01	0.255E-01
33	0.210E+12	0.464E-01	0.563E-02
34	0.210E+12	0.464E-01	0.563E-02
35	0.210E+12	0.464E-01	0.563E-02
36	0.210E+12	0.464E-01	0.563E-02
37	0.210E+12	0.464E-01	0.563E-02
38	0.210E+12	0.464E-01	0.563E-02
39	0.210E+12	0.464E-01	0.563E-02
40	0.210E+12	0.930E-01	0.255E-01

JOINT RESTRAINTS

(LX & LY = LINEAR RESTRAINT IN X & Y DIRECTION.
RZ = ROTATIONAL RESTRAINT ABOUT Z AXIS.
1000.000 = FREE)

JOINT	LX(M)	LY(M)	RZ(RAD)
1	0.000	0.000	1000.000
2	1000.000	1000.000	1000.000
3	1000.000	1000.000	1000.000
4	1000.000	1000.000	1000.000
5	1000.000	1000.000	1000.000
6	1000.000	1000.000	1000.000
7	1000.000	1000.000	1000.000
8	1000.000	1000.000	1000.000
9	1000.000	1000.000	1000.000
10	1000.000	1000.000	1000.000
11	1000.000	1000.000	1000.000
12	0.000	0.000	1000.000
13	1000.000	1000.000	1000.000
14	1000.000	1000.000	1000.000
15	1000.000	1000.000	1000.000
16	1000.000	1000.000	1000.000
17	1000.000	1000.000	1000.000
18	1000.000	1000.000	1000.000
19	1000.000	1000.000	1000.000
20	1000.000	1000.000	1000.000
21	1000.000	1000.000	1000.000
22	1000.000	1000.000	1000.000
23	1000.000	1000.000	1000.000
24	1000.000	1000.000	1000.000
25	1000.000	1000.000	1000.000
26	1000.000	1000.000	1000.000
27	1000.000	1000.000	1000.000
28	1000.000	1000.000	1000.000
29	1000.000	1000.000	1000.000
30	1000.000	1000.000	1000.000
31	1000.000	1000.000	1000.000
32	1000.000	1000.000	1000.000
33	1000.000	1000.000	1000.000
34	1000.000	1000.000	1000.000
35	1000.000	1000.000	1000.000
36	1000.000	1000.000	1000.000
37	1000.000	1000.000	1000.000
38	1000.000	1000.000	1000.000

JOINT FORCES

(PX & PY = FORCE IN X & Y DIRECTION.
CZ = COUPLE ABOUT Z AXIS)

JOINT	PX(N)	PY(N)	CZ(NM)
1	-410.00	0.00	0.00
2	0.00	0.00	0.00
3	0.00	0.00	0.00
4	0.00	0.00	0.00
5	0.00	0.00	0.00
6	-23100.00	-22300.00	0.00
7	0.00	0.00	0.00
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
11	60000.00	-22072990.00	630000.00
12	420.00	0.00	0.00
13	0.00	0.00	0.00
14	0.00	0.00	0.00
15	0.00	0.00	0.00
16	0.00	0.00	0.00
17	26300.00	-17200.00	0.00
18	0.00	0.00	0.00
19	0.00	0.00	0.00
20	0.00	0.00	0.00
21	0.00	0.00	0.00
22	60000.00	-22072990.00	630000.00
23	0.00	0.00	0.00
24	0.00	0.00	0.00
25	0.00	0.00	0.00
26	0.00	0.00	0.00
27	0.00	0.00	0.00
28	0.00	0.00	0.00
29	0.00	0.00	0.00
30	0.00	0.00	0.00
31	0.00	0.00	0.00
32	0.00	0.00	0.00
33	0.00	0.00	0.00
34	0.00	0.00	0.00
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00

FORCE NUMBER	FORCE(N OR N/M)	POSITION
1	-565.00	0.00
2	-778.00	0.00
3	-1067.00	0.00
4	-1459.00	0.00
5	-1985.00	0.00
6	-1985.00	0.00
7	-2678.00	0.00
8	-3575.00	0.00
9	-4691.00	0.00
10	11210.00	0.50
11	585.00	0.00
12	815.00	0.00
13	1139.00	0.00
14	1598.00	0.00
15	2250.00	0.00
16	2250.00	0.00
17	3188.00	0.00
18	4553.00	0.00
19	6569.00	0.00
20	11210.00	0.50
21	37.00	0.00
22	79.00	0.00
23	131.00	0.00
24	189.00	0.00
25	251.00	0.00
26	306.00	0.00
27	-47.00	0.00
28	-103.00	0.00
29	-169.00	0.00
30	-246.00	0.00
31	-324.00	0.00
32	-397.00	0.00
33	-685.00	0.00
34	-955.00	0.00
35	-1132.00	0.00
36	-1194.00	0.00
37	-1158.00	0.00
38	-1048.00	0.00
39	214.00	0.00
40	372.00	0.00
41	550.00	0.00
42	724.00	0.00
43	902.00	0.00
44	1098.00	0.00
45	-277.00	0.00
46	-481.00	0.00
47	-707.00	0.00
48	-938.00	0.00
49	-1168.00	0.00
50	-1422.00	0.00

INTERMEDIATE FORCES

FORCE NO.	MEMBER	DIRECTION	TYPE
1	1	1	2
2	2	1	2
3	3	1	2
4	4	1	2
5	5	1	2
6	6	1	2
7	7	1	2
8	8	1	2
9	9	1	2
10	10	1	1
11	11	1	2
12	12	1	2
13	13	1	2
14	14	1	2
15	15	1	2
16	16	1	2
17	17	1	2
18	18	1	2
19	19	1	2
20	20	1	1
21	21	1	2
22	22	1	2
23	23	1	2
24	24	1	2
25	25	1	2
26	26	1	2
27	21	2	2
28	22	2	2
29	23	2	2
30	24	2	2
31	25	2	2
32	26	2	2
33	27	2	2
34	28	2	2
35	29	2	2
36	30	2	2
37	31	2	2
38	32	2	2
39	33	1	2
40	34	1	2
41	35	1	2
42	36	1	2
43	37	1	2
44	38	1	2
45	33	2	2
46	34	2	2
47	35	2	2
48	36	2	2
49	37	2	2
50	38	2	2

LOCAL MEMBER FORCES

MEMBER/JOINT	FMX (N)	FMY (M)	CMZ (NM)
1/1	-16437.38	22036780.00	-92237.31
1/2	10787.38	-22036780.00	-43897.67
2/2	-10784.75	22036800.00	43913.67
2/3	3004.75	-22036800.00	-112877.60
3/3	-3006.06	22036780.00	112894.30
3/4	-7663.94	-22036780.00	-89626.31
4/4	7661.25	22036700.00	89637.63
4/5	-22251.25	-22036700.00	59926.33
5/5	22350.75	22036740.00	-59875.85
5/6	-27313.25	-22036740.00	121689.80
6/6	-54851.13	22075230.00	-474516.70
6/7	39963.63	-22075230.00	118975.70
7/7	-39968.56	22075140.00	-118895.60
7/8	13188.56	-22075140.00	-146906.30
8/8	-13203.81	22075120.00	146918.30
8/9	-22546.19	-22075120.00	-100213.30
9/9	22543.25	22075100.00	100222.30
9/10	-69453.25	-22075100.00	359751.60
10/10	69461.94	22074880.00	-359681.80
10/11	-58252.00	-22074880.00	678929.80
11/12	9110.81	22453090.00	4.00
11/13	-3260.81	-22453090.00	61842.00
12/13	3261.56	22453100.00	-61839.34
12/14	4888.44	-22453100.00	53687.34
13/14	-4889.69	22453090.00	-53695.34
13/15	16279.69	-22453090.00	-52189.66
14/15	-16280.19	22453020.00	52190.66
14/16	32260.19	-22453020.00	-294881.60
15/16	-32147.50	22462990.00	294934.90
15/17	37772.50	-22452990.00	-382339.90
16/17	124770.50	22199410.00	1231970.00
16/18	-107895.50	-22199410.00	-359475.90
17/18	107863.80	22199340.00	359540.60
17/19	-75983.81	-22199340.00	559669.30

18/19	75968.25	22199330.00	-559660.30
18/20	-30438.81	-22199330.00	1091670.00
19/20	30435.56	22199310.00	-1091663.00
19/21	35254.44	-22199310.00	1067582.00
20/21	-35225.00	22199040.00	-1067500.00
20/22	46435.00	-22199040.00	863291.80
21/1	6065.22	-302406.90	92241.38
21/23	-5383.22	302403.00	-26974.43
22/23	5387.09	-302445.00	26971.40
22/24	-3907.10	302455.00	26015.09
23/24	3904.00	-302468.00	-26009.86
23/25	-1466.00	302472.00	56624.92
24/25	1464.68	-302474.50	-56618.19
24/26	2072.32	302495.50	53154.62
25/26	-2082.32	-302497.50	-53146.70
25/27	6755.32	302506.50	2769.47
26/17	-18309.40	-302310.80	-186954.20
26/27	12044.40	302393.30	-2760.03
27/17	-40235.56	41920.00	-662496.20
27/28	33522.55	-41920.00	301083.40
28/28	-33525.00	41984.00	-301074.50
28/29	25025.20	-41984.00	40535.41
29/29	-25024.36	41904.00	-40534.55
29/30	15062.77	-41904.00	-135856.40
30/30	-15063.25	41920.00	135852.00
30/31	4556.06	-41920.00	-222171.90
31/31	-4556.47	41840.00	222162.20
31/32	-5749.72	-41840.00	-216848.20
32/6	16028.70	41760.00	-110069.00
32/32	-5758.30	-41760.00	216821.50
33/6	34815.68	-162132.30	463139.40
33/33	-30717.69	162283.80	-79263.75
34/33	22453.75	-163853.00	79230.44
34/34	-16373.75	163763.00	114898.30
35/34	16383.43	-163838.90	-114873.90
35/35	-7427.44	163681.00	233927.90

36/35	7397.94	-163794.00	-233883.80
36/36	4550.05	163630.00	248621.30
37/36	-4419.95	-163704.00	-248577.90
37/37	19175.93	163496.00	130591.30
38/37	-19190.07	-163470.00	-130548.90
38/38	37154.05	163218.00	-151171.90
39/22	-28637.38	-164704.00	-374864.40
39/38	28637.38	164704.00	131195.00
40/11	1686.66	1776.00	-48883.25
40/22	-1686.66	-1776.00	141649.30

APPENDIX E

Combined Stresses

COMBINED STRESSES

Consider a cylinderical member of outer diameter 'd' and a wall thickness 't' under the action of the forces, F_x and F_y, and moment, Q, as shown in Fig.( ).

Inner diameter, $d_i = d - 2t$

Cross sectional area, $A = \frac{\pi}{4}(d^2 - d_i^2)$

Moment of inertia, $I = \frac{\pi}{64}(d^4 - d_i^4)$

Modulus of section for bending, $Z_b = \frac{I}{d/2} = \frac{\pi}{32}\left(\frac{d^4 - d_i^4}{d}\right)$

Direct stress, $\delta_n = \frac{F_y}{A}$

Bending stress, $\delta_b = \pm \frac{Q}{Z_b}$

Total tension or compression stress, $\delta = \pm \delta_b + \delta_n$

Maximum shearing stress due to F_x is given by:-

$$\tau = \frac{F_x}{2It} \cdot M.O.A.$$

where M.O.A. is the first moment of area for the semi-ring given in Fig.(50).

$$M.O.A. = 2 \int_0^{\pi/2} r d\phi . t . r . \sin\phi = 2tr^2 \int_0^{\pi/2} \sin\phi \, d\phi$$

$$= 2tr^2[-\cos\phi]_0^{\pi/2} = 2tr^2 \quad \text{where} \quad r = \frac{d_i}{2}$$

Thus, $\tau = \frac{F_x}{2It} \cdot 2tr^2 = \frac{F_x \cdot d_i^2}{4I}$

If the hoop stresses are to be considered, then

$$\text{Hoop stress, } \delta_h = \frac{\rho \cdot g \cdot H_s (d - t)}{2t}$$

Principal Stresses

The principal stresses can be calculated as follows:-

$$\delta_1 = \tfrac{1}{2}[(\delta - \delta_h) + \sqrt{((\delta - \delta_h)^2 + 4\tau^2)}]$$

$$\delta_2 = \tfrac{1}{2}[(\delta - \delta_h) - \sqrt{((\delta - \delta_h)^2 + 4\tau^2)}]$$

$$\tau_m = \tfrac{1}{2}(\delta_1 - \delta_2)$$

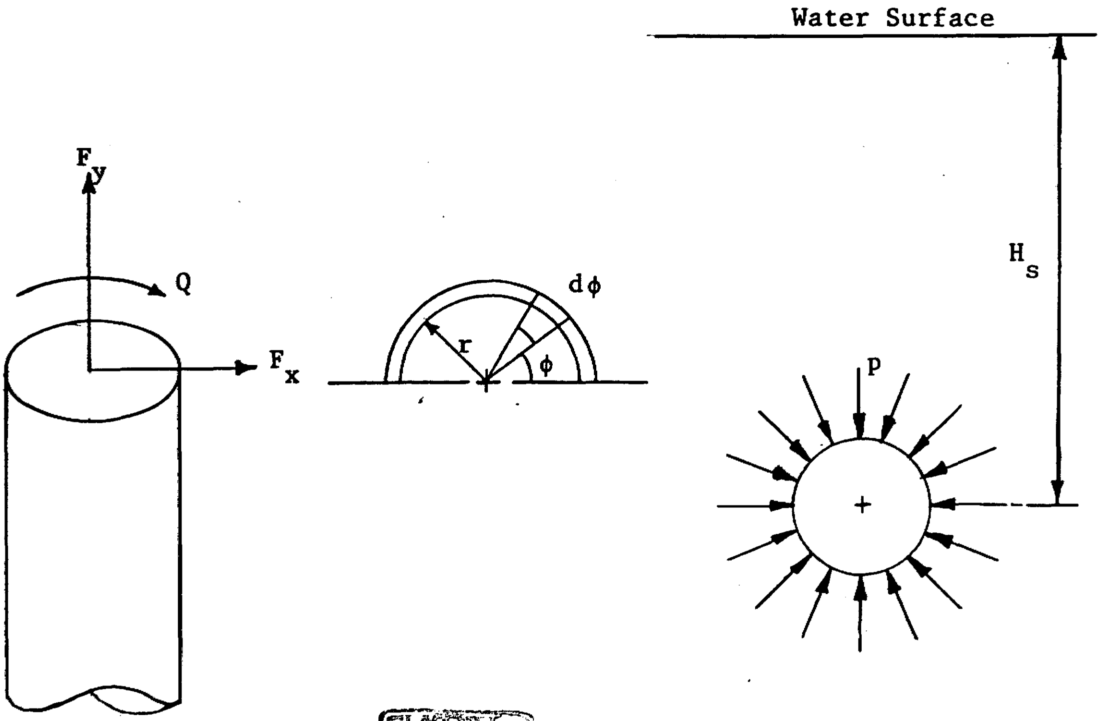


Fig.50 Forces and Moment on Members