②

UNIVERSITY OF MIAMI

ROSENSTIEL SCHOOL OF MARINE AND ATMOSPHERIC SCIENCE

RSMAS-TR88-004

AD-A203 782

IMPLEMENTATION OF AN EXPERT SYSTEM
FOR DESIGN OF
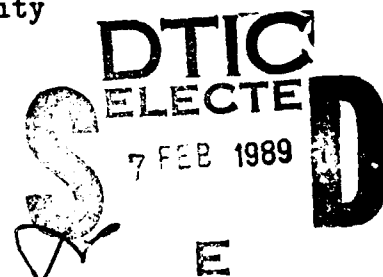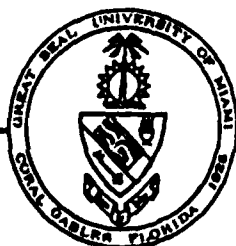SINGLE-POINT SUBSURFACE OCEANOGRAPHIC MOORINGS

by

Santhosh Kumaran and Richard A. Skop

December 1988

Approved for public release. Distribution unlimited.

Prepared for:

Naval Ocean Research and Development Activity
Department of the Navy

DTIC
ELECTE
7 FEB 1989
E

89   2   7   047

MIAMI, FLORIDA 33149

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS			
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release. Distribution unlimited.			
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) RSMAS-TR-88-004		5. MONITORING ORGANIZATION REPORT NUMBER(S)			
6a. NAME OF PERFORMING ORGANIZATION Division of Applied Marine Physics	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION			
6c. ADDRESS (City, State, and ZIP Code) Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL 33149		7b. ADDRESS (City, State, and ZIP Code)			
8a. NAME OF FUNDING/SPONSORING ORGANIZATION NORDA	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-86-K-6001			
8c. ADDRESS (City, State, and ZIP Code) Stennis Space Center, MI 39529		10. SOURCE OF FUNDING NUMBERS			
		PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION

11. TITLE (Include Security Classification) Implementation of an Expert System for Design of Single-Point Subsurface Oceanographic Moorings

12. PERSONAL AUTHOR(S) Santhosh Kumaran and Richard A. Skop

13a. TYPE OF REPORT Interim	13b. TIME COVERED FROM 8/87 TO 12/88	14. DATE OF REPORT (Year, Month, Day) December 1988	15. PAGE COUNT

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Expert systems, Moorings, Oceanographic moorings

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The design of single-point subsurface moorings is done manually at present with the help of some computer programs. These computer programs are used for analyzing the mooring, but the setting up of the initial mooring configuration and the subsequent modifications on the basis of the results of the analysis are done by the design engineer.

An expert system for mooring design is developed to eliminate the human expert from the design process and thus to enable a novice to design a mooring by himself. Using the expert system, an optimum least-weight in air design can be developed in much less time than is usually required in conventional procedures. Perhaps the most significant advantage is that the system can serve as a vehicle for effective transfer of present day expertise for future applications.

(see reverse side)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL

i

The system is developed and implemented on an IBM PC/AT. It has a user-friendly, interactive, menu-driven input procedure and a sophisticated output facility. The design process is totally automated and the requirement to consult a human expert is eliminated. The system has tremendous flexibility and a knowledge engineer can easily adapt it to the specific requirements of a particular user. The concept of machine learning is introduced by recording the failure data and using this information in the later decision making processes. A CAD package, AUTOCAD, is used to generate the drawings and an interface is developed between the CAD package and the expert system so that the former is transparent to the user.

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	

By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

TABLE OF CONTENTS

1. INTRODUCTION

The design of single-point subsurface moorings is done manually at present with the help of some computer programs. These computer programs are used for analyzing the mooring, but the setting up of the initial mooring configuration and the subsequent modifications on the basis of the results of the analysis are done by the design engineer. The design engineer's role calls for a measure of expertise in the field which accrues from years of experience in designing the mooring, deploying it and watching it's performance over the deployment period. S.L.Wood [1987] studied the feasibility of implementing an Expert System to design single-point subsurface moorings and concluded that it is possible to replace the human design engineer with a computer-based expert assistant. Wood suggested that a commercially available expert system shell, such as INSIGHT 2+, be used for developing the system so that the implementation will be easier, less expensive and more effective. He also recommended the use of a CAD package for the output of the final detailed design.

An expert system for mooring design will eliminate the human expert from the design process and thus enable a novice to design a mooring by himself. The time spent in the design process will be much less and the final output will be an optimum least–weight in air design, given a set of input data. Least–weight in air is used as the optimization criterion since it is closely related to least cost of the mooring and, more importantly, to ease of handling at sea. Perhaps the most significant advantage is that the system will serve as a vehicle for effective transfer

of present day expertise for future applications.

Thus the objective is to develop a system which can perform the following:

1. Gather necessary information from the user in a user-friendly interactive mode;

2. Interact with a data base of mooring parts and allow the user to update the data base;

3. Come up with a minimum weight in air design, if possible, or display an appropriate error message;

4. Interact with a CAD package and produce a graphic output of the final design without the direct involvement of the user;

5. Provide the user with a hardcopy of the results of the analysis if he desires so;

6. Modify the design to suit the specific needs of the user;

7. Advise the user on the input modifications in case of a failure.

2. SYSTEM OVERVIEW

A thorough study of the design process reveals that there are 5 entities involved in it, namely,

1. The data base of mooring parts;

2. The design knowledge of the experts;

3. Algorithmic programs for analyzing the mooring;

4. Standard procedures for developing the design;

5. Production of a detailed drawing to represent the final design;

The expert system coordinates all 5 of these and acts as an Artificial Intelligence executive program.

Choice of a programming language is a fundamental question to be resolved before proceeding with the development of the system. Recalling Nicklaus Wirth's famous identity, "Algorithms + Data structures = Programs", it is clear that the programming language to be used should have excellent data structuring capabilities and should be conducive to structured programming, which means that PASCAL is an automatic choice.

The data base is implemented as a set of PASCAL sequential files and a menu-driven data base editor has been developed to help the user create and maintain the data base. The design knowledge of the experts is represented in the form of a series of knowledge bases, linked together. These knowledge bases are created using the INSIGHT 2+ expert system shell.

Mooring analysis programs include the no current static analysis, static analysis under the influence of a velocity profile and launch analysis. These algorithmic routines and the procedures for setting-up and step-wise refinement of the design are coded as PASCAL programs.The system has a software interface to communicate with the CAD package so that the CAD package will be transparent to the user.

Schematic representation of various components of the system and their relationships with each other are shown in figure 1.
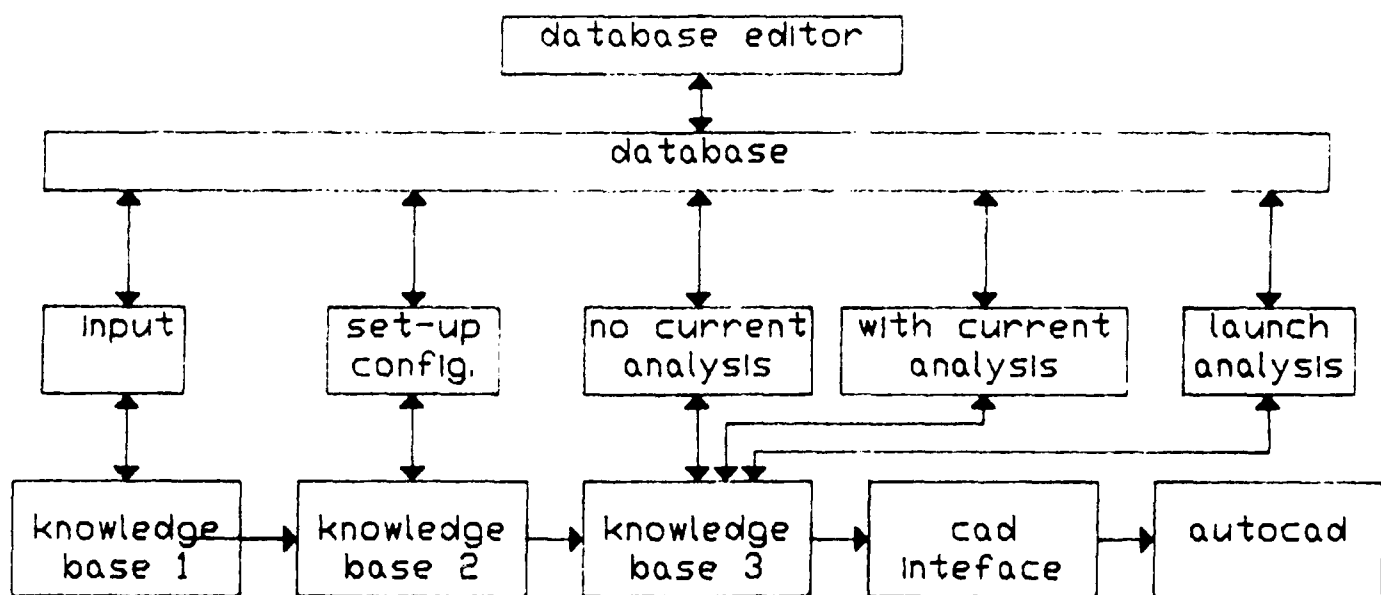
Figure 1: system overview

3. DATA BASE ORGANIZATION

The data base is implemented as a set of 3 PASCAL sequential files, namely,

1. Ropes and chains;

2. Instruments;

3. Flotations.

1. Ropes and chains.

The following types of items make up this portion of the data base:

    1. Steel Wire Rope;

    2. Steel EM Cable;

    3. Kevlar Rope;

    4. Kevlar EM Cable;

    5. Polypropyline Rope;

    6. Nylon Rope;

    7. Chain.

Each record in this file has the following structure:

    1. code   :string of 3 characters;

    2. type   :string of 35 characters;

    3. weight in air   :real number(kilograms/meter);

    4. rigidity (AE)   :real number(kilograms);

    5. weight in water   :real number(kilograms/meter, +ve if buoyant);

    6. drag coefficient   :real number;

7. diameter   :real number(meters);

8. breaking strength   :real number(kilograms);

9. cost   :optional, real number(US dollars/meter);

10. instrument capacity   :integer(see note below).

Note: Instrument capacity is applicable only for electro–mechanic cables, in which case it means the number of hydrophones that can be connected to the cable.

Given below is an example:

1. code   :'KEM';

2. type   :'16–PR KEV ELECTRO–MECHANIC CABLE';

3. weight in air   :0.30603 kilograms/meter;

4. rigidity   :136200 kilograms;

5. weight in water   :-0.20853 kilograms/meter;

6. drag coefficient   :1.5;

7. diameter   :0.01905 meters;

8. breaking strength   :5000 kilograms;

9. cost   :$ 100;

10. instrument capacity   :16.

2. Instruments

The instrument file consists of records falling into the following categories:

1. Hydrophones;

2. Current meters;

3. Acoustic releases;

4. Tension recorders;

5. Transponders.

Structure of an instrument record is as follows:

1.code	:string of 3 characters;
2.type	:string of 35 characters;
3.length	:real number(meters);
4.area	:real number(square meters);
5.weight in air	:real number(kilograms);
6.weight in water	:real number(kilograms,+ve if buoyant);
7.maximum depth	:real number(meters);
8.drag coefft	:real number;
9.maximum tension	:real number(kilograms);
10.cost	:optional, real number(US dollars);
11.online	:boolean(see note below).

Note: 'Online' will have a value of TRUE if the instrument is connected in line with the mooring cable and FALSE otherwise.

Following is an example of an instrument record:

1.code	:'HPN';
2.type	:'AMBIENT HYDROPHONE';
3.length	:0.12 meters;
4.area	:0.012077 square meters;
5.weight in air	:0.681 kilograms;

6.weight in water	:-0.641 kilograms;
7.maximum depth	:6000 meters;
8.drag coefft	:0.6;
9.maximum tension	:10896 kilograms;
10.cost	:$ 200;
11.online	:FALSE.

3. Flotations.

Typical items in the flotation data base are:

1. Glass balls;

2. Syntactic foam spheres;

3. Steel spheres.

Fields in a flotation record are described below:

1.code	:string of 3 characters;
2.type	:string of 35 characters;
3.weight in air	:real number(kilograms);
4.area	:real number(square meters);
5.weight in water	:real number(kilograms,+ve if buoyant);
6.depth rating	:real number(meters);
7.drag coefft	:real number;
8.cost	:optional, real number(US dollars).

Given below is an example flotation record:

1.code	:'GBL';
2.type	:'17 INCH DIA GLASS BALLS';
3.weight in air	:17.7 kilograms;
4.area	:0.13935 square meters;
5.weight in water	:25.43 kilograms;
6.depth rating	:6000 meters;
7.drag coefft	:0.5;
8.cost	:$ 500.

Code and type together will uniquely identify a record in the data base. All records belonging to a particular category will have the same code, for example, 'KEM' denotes the Kevlar EM Cable, 'GBL' represents glass balls and 'HPN' stands for hydrophones.

A menu driven interactive editor is provided for creating the data base and to help the user maintain it by selective updating. Updating the data base can be performed by adding a record, deleting a record or by modifying a record. Each time the data base is edited, it is sorted in the increasing order of the unit weight in air of the items.

4. INTERNAL REPRESENTATION OF THE MOORING

The key idea in the internal representation of the mooring is that the entire set of mooring parts can be segregated into 2 subsets, namely,

1. Mooring components;

2. Mooring accessories.

Mooring components are those parts which are subjected to tension and the remaining parts fall in the category of mooring accessories. The fields in a mooring component record are as follows:

1. Depth at top;

2. Depth at bottom;

3. Maximum tension;

4. Type.

Following is the structure of a mooring accessory record:

1. Depth;

2. Type.

Thus the entire mooring is represented internally by two separate files, one consisting of mooring component records and the other of mooring accessory records. As the design process rolls on, these files will be processed, adding new records to them, deleting records or modifying records.

5. ANALYSIS ALGORITHMS

Methodology to find the static equilibrium configuration of the mooring under the influence of a velocity profile is well established [Skop, 1988]. So is the procedure to find tension in the mooring during an anchor last deployment [Heinmiller, 1976].

To find the static equilibrium with current, a co-planar velocity profile is assumed. This will always give the worst case scenario and given the uncertainty regarding the velocity profile at the site of deployment, it is advisable to use a co-planar velocity profile for doing the analysis.

The data-structure used to represent the mooring internally and described in the earlier section is inadequate to perform the static equilibrium analysis. The mooring has to be split into a number of finite elements for the purpose of analyzing it. Hence a mooring segment file is created from the mooring component file with each record having the following fields :

1. code of the parent component;

2. type of the parent component;

3. original position;

4. previous position of both ends of the segment;

5. current position of both ends of the segment;

6. reaction vector at both ends of the segment;

7. hydrodynamic force vector acting on the segment;

8. strain at both ends of the segment.

The length of the individual segment is a variable parameter, which has a minimum value of 1m and a maximum value depending on the length of the component since the maximum number of segments permitted for a component is set to 50.

The current analysis gives the tension along the mooring when acted upon by the user specified velocity profile. The values of tension and slope at the anchor are used to design the anchor using the formula given by Wood [1987]. Once the anchor size is decided, the launch analysis can be done.

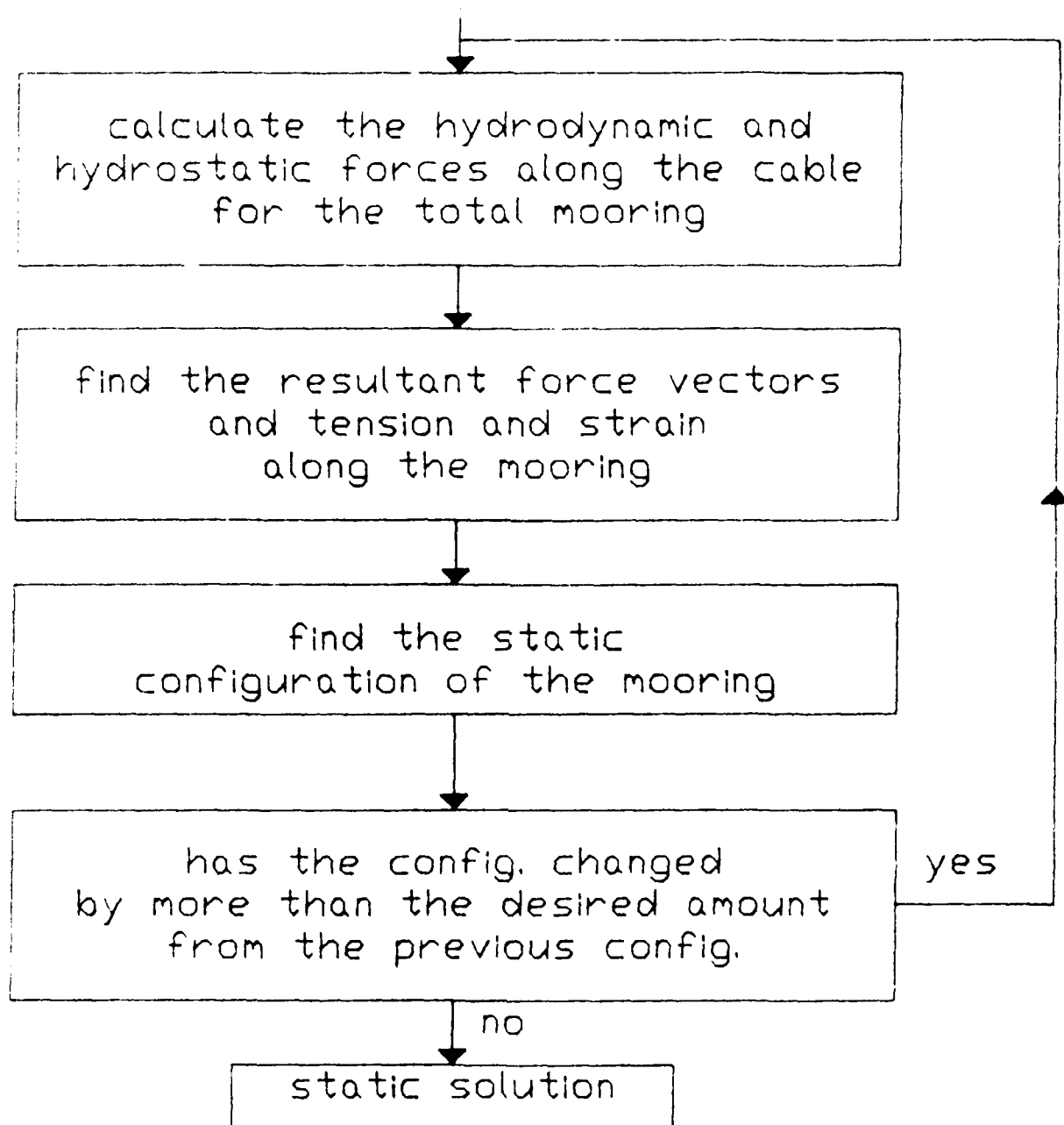Fig.2 shows the flow chart for the static equilibrium analysis under the influence of a velocity profile.

Figure 2: static equilibrium analysis

6. KNOWLEDGE BASE REPRESENTATION

The difference between a traditional application program and an Expert System is worth exploring at this point. In the conventional program, the knowledge is embedded within the algorithmic procedures and hence obscured by the syntax of the programming language. The new concept of knowledge engineering involves separation of this knowledge from the algorithmic programs and representation of it as a knowledge base. This will permit the growth of the knowledge base caused either directly by the knowledge engineer or more ambitiously by the system itself.

The system has three knowledge bases, linked together, which form the nucleus of the entire package. Figure 3 illustrates the forward chained knowledge base structure. Within the individual knowledge bases, backward chaining is used to represent the knowledge. The first knowledge base collects the input data from the user and then decides whether the data set contains adequate information for designing the mooring. If the input data is incomplete, the user will be prompted for further input. Control is transferred to the second data base if the system is ready to proceed with the design.

The second knowledge base applies the design knowledge to the input data and selects the type of mooring and puts together a rudimentary design. Figure 4 shows the structure of this knowledge base. This knowledge base also creates the two mooring files, component list and accessory list. If the selection of the

type of mooring and the creation of the internal files are successful, then the third knowledge base is activated.

The third knowledge base performs the analyses on the mooring and modifies the design on the basis of the results of the analyses. The structure of this knowledge base is given in figure 5. It acts like an Artificial Intelligence executive program invoking the necessary routines in a cycle till it gets a satisfactory design. Once the final design is obtained, the control is passed to a filter program which generates the drawing file compatible with the CAD package. Then the plot routine of the CAD package is invoked to generate the drawing.

Transfer of parameters between the knowledge bases is accomplished using a temperory disc file. The knowledge bases interact with the data base through PAS-CAL programs. It is not possible to represent the complex data structures using the knowledge bases created using Insight 2+ expert system shell. This , in fact, is the price we have to pay for the easiness in the implementation. Hence PASCAL programs are frequently used by the knowledge bases to create and manipulate complex data structures associated with the mooring design.

```
┌─────────────────────────────────────────┐
│          collect all the input info      │
│     from the user and create necessary   │
│        data-structures to store them     │
│   proceed to next link if input is complete │
└─────────────────────────────────────────┘
                    ▼
┌─────────────────────────────────────────┐
│    design a rudimentary configuration    │
│   create internal files to store them    │
│       proceed to next link if all ok     │
└─────────────────────────────────────────┘
                    ▼
┌─────────────────────────────────────────┐
│        analyze and update the design     │
│  repeat till a satisfactory design is evolved │
│           output the final design        │
└─────────────────────────────────────────┘
```
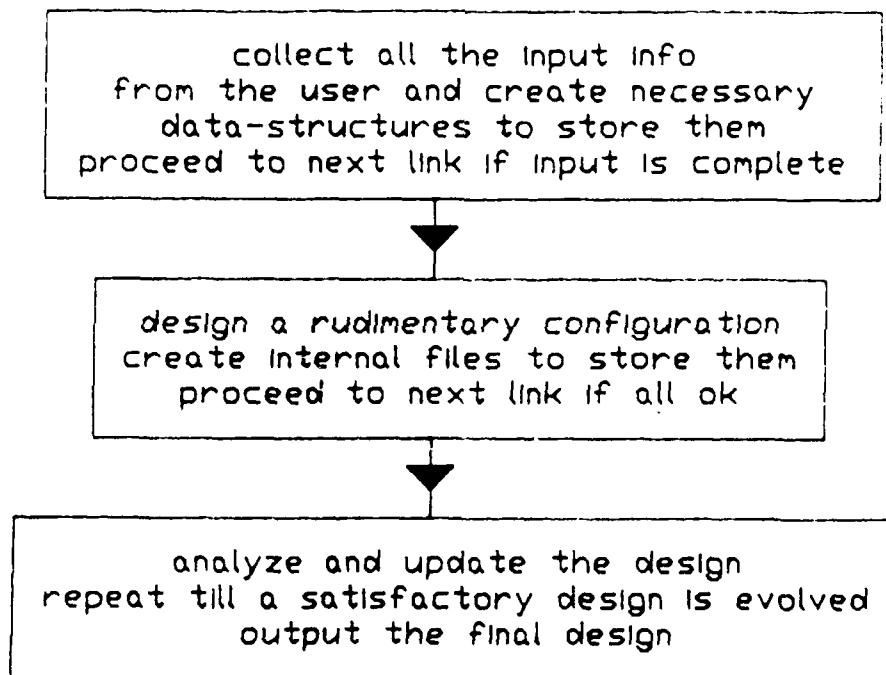
Figure 3: forward chained knowledge base structure

```
┌─────────────────────┐
│      selected       │
│    mooring type     │
└─────────────────────┘
           ▲
           │
┌─────────────────────┐
│   we have created   │
│  the internal files │
└─────────────────────┘
           ▲
           │
┌─────────────────────┐
│        run          │
│    initconf.com     │
└─────────────────────┘
           ▲
           │
┌─────────────────────┐
│       we have       │
│  the type of mooring│
└─────────────────────┘
           ▲
           │
┌─────────────────────┐
│       we have       │
│ the top configuration│
└─────────────────────┘
           ▲
           │
┌─────────────────────────┐
│        we have          │
│ the bottom configuration│
└─────────────────────────┘
```
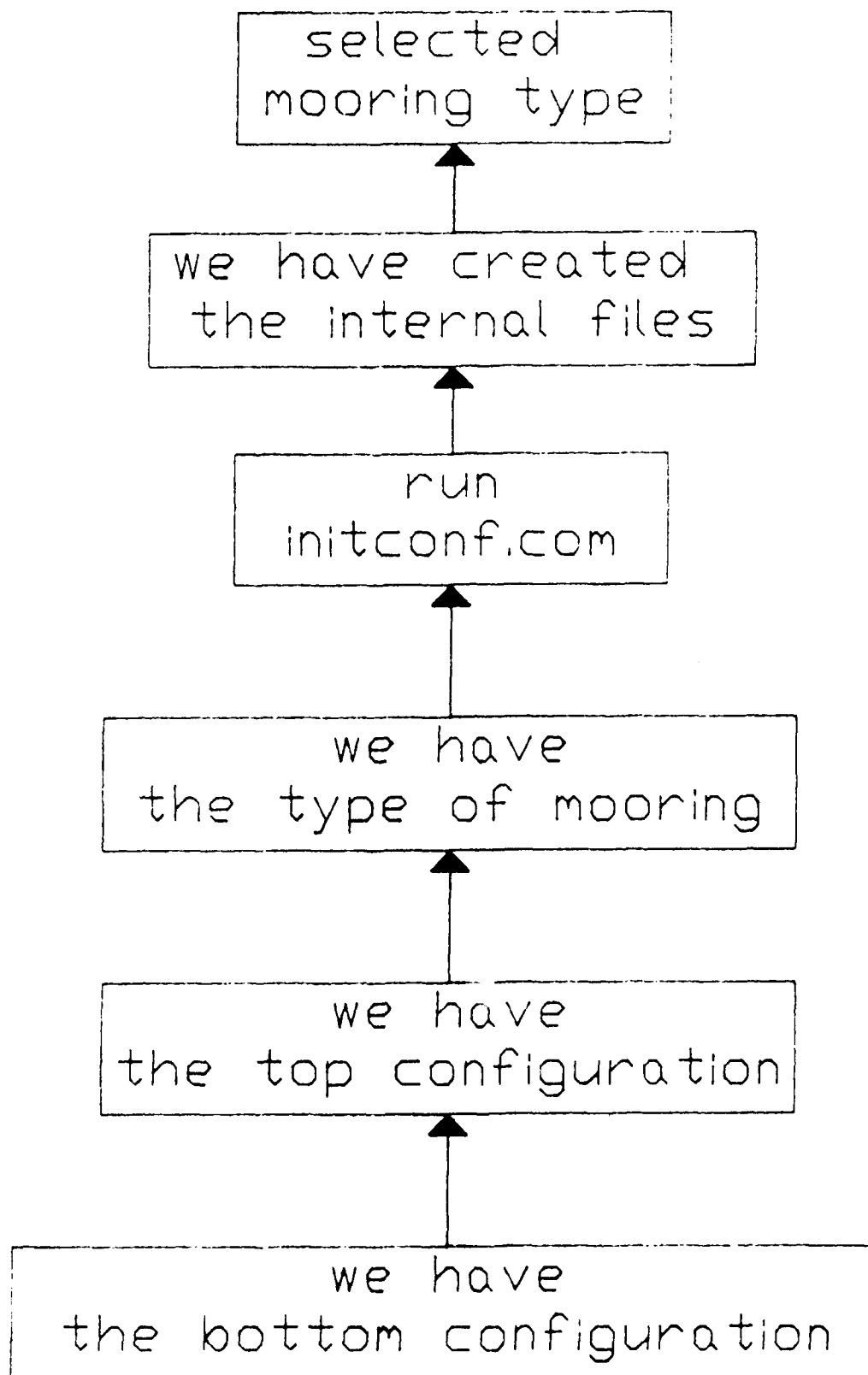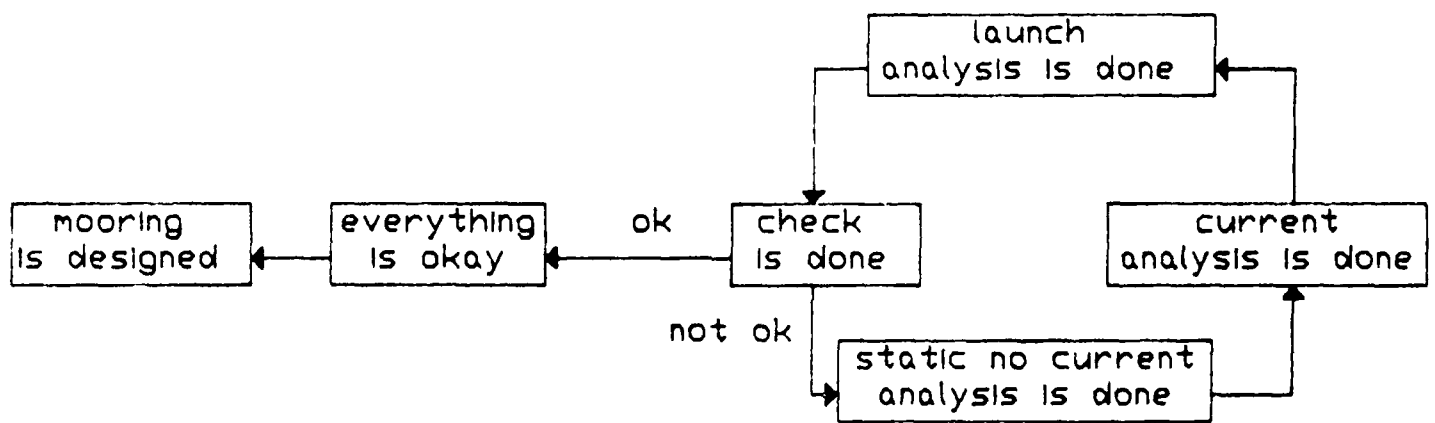
Figure 4: knowledge base 2

Figure 5: knowledge base 3

6a. INPUT PROCEDURE

The input procedure is user-friendly, interactive and menu-driven. The user will be prompted for the following information:

1. Particulars of the array.

This includes the number and type of instruments being used and their spacing. To help the user define the array, the instrument database will be displayed on the screen so that the user can easily pick up the instruments he needs. A newly defined array will be given a name and stored on the disk, thus providing an option to the user to use an existing instrument array with or without modifications. Since any number of types of instruments can be used in the array, the user has to input the distance between lower-most instrument of every type and the lower-most instrument in the array.

2. Position of the array and the waterdepth.

The user will be prompted for the waterdepth and the distance between the sea-bottom and the lowest instrument in the array. The acceptable range for waterdepth is between 30 m and 6000 m.

3. Velocity profile.

The user has an option to either use a 'canned' profile or generate his own profile. To generate the profile, he needs to input the depth and velocity at one or more points along the water column. The velocity in a region between two user specified points is found by linear interpolation. If the velocity at the surface

or bottom is not specified, then a uniform current layer is assumed there with a thickness equal to the distance from surface or bottom to the nearest user specified point.

To generate the 'canned' profile, the user needs to input the surface velocity and the thickness of the constant velocity layer at the surface. The details regarding the generation of canned profile can be found in Wood [1987].

4. Motion restrictions.

Three types of motion restrictions can be specified for an instrument.

1. Dip : the vertical displacement of the instrument from it's designated position.

2. Excursion : the horizontal displacement of the instrument from it's designated position.

3. Tilt angle : Some instruments are sensitive to the tilt angle and for such instruments, it should be ensured that the tilt angle is not exceeding a pre-defined limit.

The system will also prompt for sea-floor slope, type of sea-bed material and deployment period. But the user has an option in these cases to respond that these are unknowns to him, whereupon the system will assaign default values to these parameters.

6b. SETTING UP THE INITIAL CONFIGURATION

Wood [1987] has developed a classification tree for subsurface, single-point moorings [fig.6]. A set of 'rules of thumb' was also compiled by him to represent the design knowledge of the experts. The classification tree is made use of in selecting the type of mooring and the 'rules of thumb' help to choose a rudimentary configuration. Subsequently, two internal files, mooring component list and mooring accessory list, are created to represent the mooring and are stored on the disc. This design is only for the use of the system. It provides a framework on which various analyses can be performed.

Wood's classification tree consists of 28 types of moorings. The classification is done on the basis of the following factors:

1. Acoustic or non-acoustic;

2. Inside fish-byte zone or outside it;

3. Weak current region or strong current region;

4. Waterdepth less than 2000 m or greater than 2000 m;

5. Top experiment depth less than 500 m, between 500 m and 2000 m or greater than 2000 m.

Each of the 28 types can have 3 different configurations on the basis of the bottom experiment depth.

Setting up of the initial configuration is realized by conceiving the total

mooring as the assembly of three different segments , ie the top mooring configuration, the middle mooring configuration and the bottom mooring configuration. Top and bottom mooring configurations can be standardized using the 'rules of thumb' [Wood, 1987]. Thus each of the 28 types can have one of the three bottom configurations depending on the height above seafloor of the deepest instrument and one of the 4 top mooring configurations depending on the velocity profile and the top–most instrument depth. These are illustrated in figures 7 through 13.

If the distance between the acoustic release and the sea–bottom is less than 20 m, bottom–configuration–1[fig.7] is used. But if it is greater than 20 m and less than 30 m, then it is possible to include nylon as a shock–absorber and hence the configuration shown in fig.8 is preferred. If the distance is greater than 30 m, then the bottom–configuration–3[fig.9] is used.

Top configurations 1 and 2(fig.10 and fig.11 respectively) use syntactic foam sphere or steel sphere as the primary buoyancy. The former corresponds to a non–acoustic array and the latter to an acoustic array. Glass balls are used for primary buoyancy in the top configurations 3 and 4(figures 12 and 13 respectively). As before, figure 12 represents a non–acoustic array and the figure 13 an acoustic array.

The first step in the set-up procedure is selecting the type of mooring based on the input data. Then by applying the 'Rules of Thumb', the initial bottom configuration and the initial top mooring configuration are selected. These may

be later changed during the analysis. Middle mooring configuration is designed using the type of mooring selected and the array details specified by the user. By putting together these three segments, an initial design is formed. The total mooring configuration is passed to an external program using a set of parameters. The external program sets up the two internal files, mooring component list and mooring accessory list, using values of parameters it received from the knowledge base.
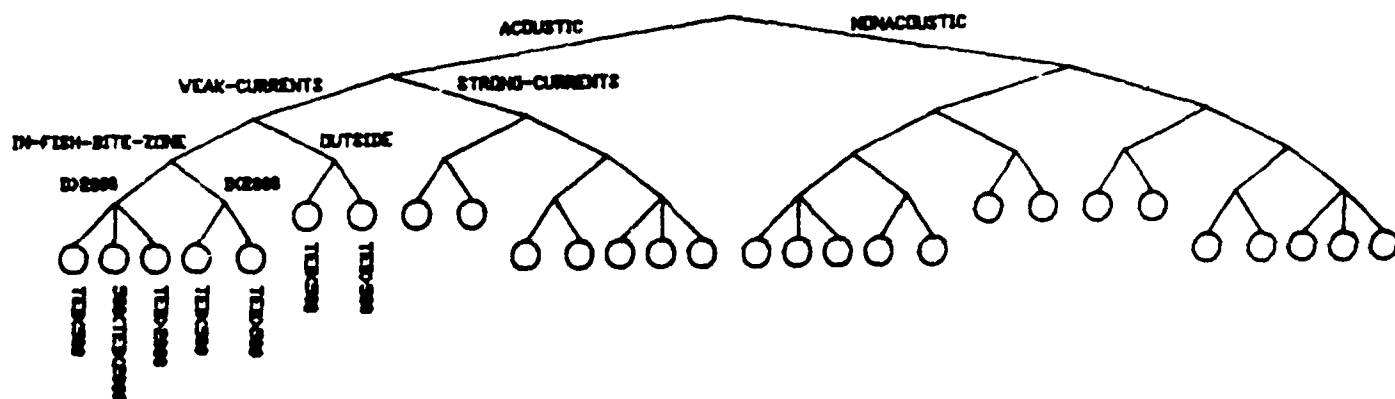
Figure 6: Classification Tree for single--point subsurface moorings

8 m 3/8" chain with
5 17" dia glass balls

dual acoustic release

7.5 m 1/2" chain with parachute
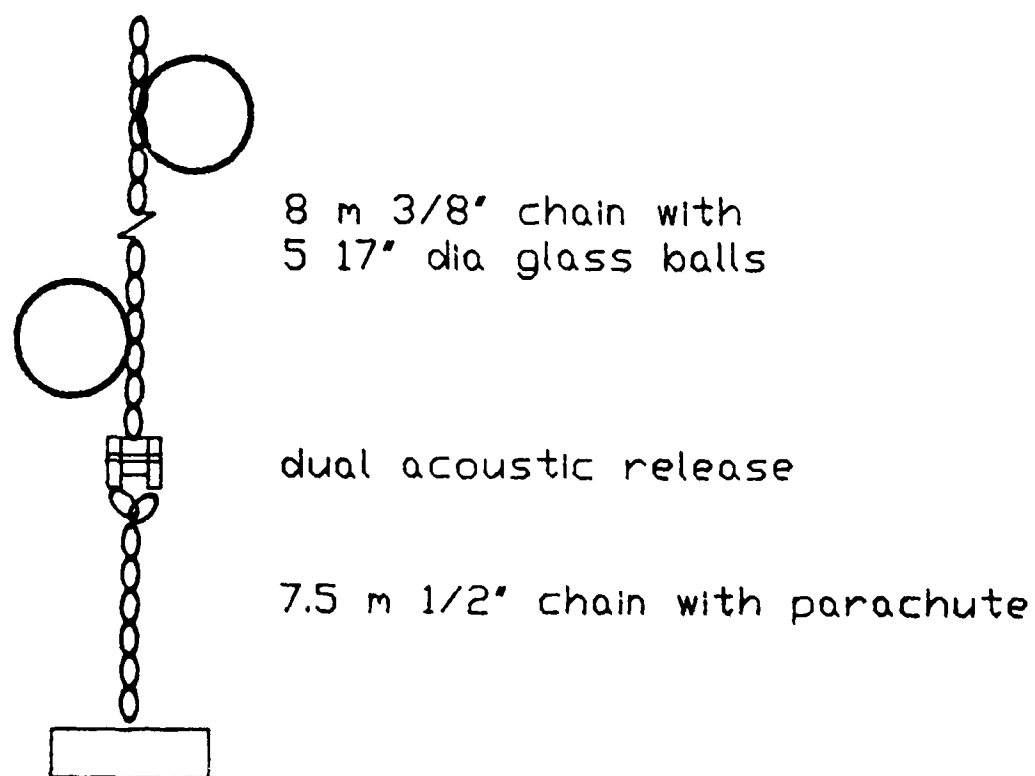
Figure 7: bottom-mooring-configuration-1(typical)

8 m 3/8" chain with
5 17" dia glass balls

dual acoustic release

5 m 1/2" chain

10 m 1/2" nylon rope

5 m 1/2" chain with parachute
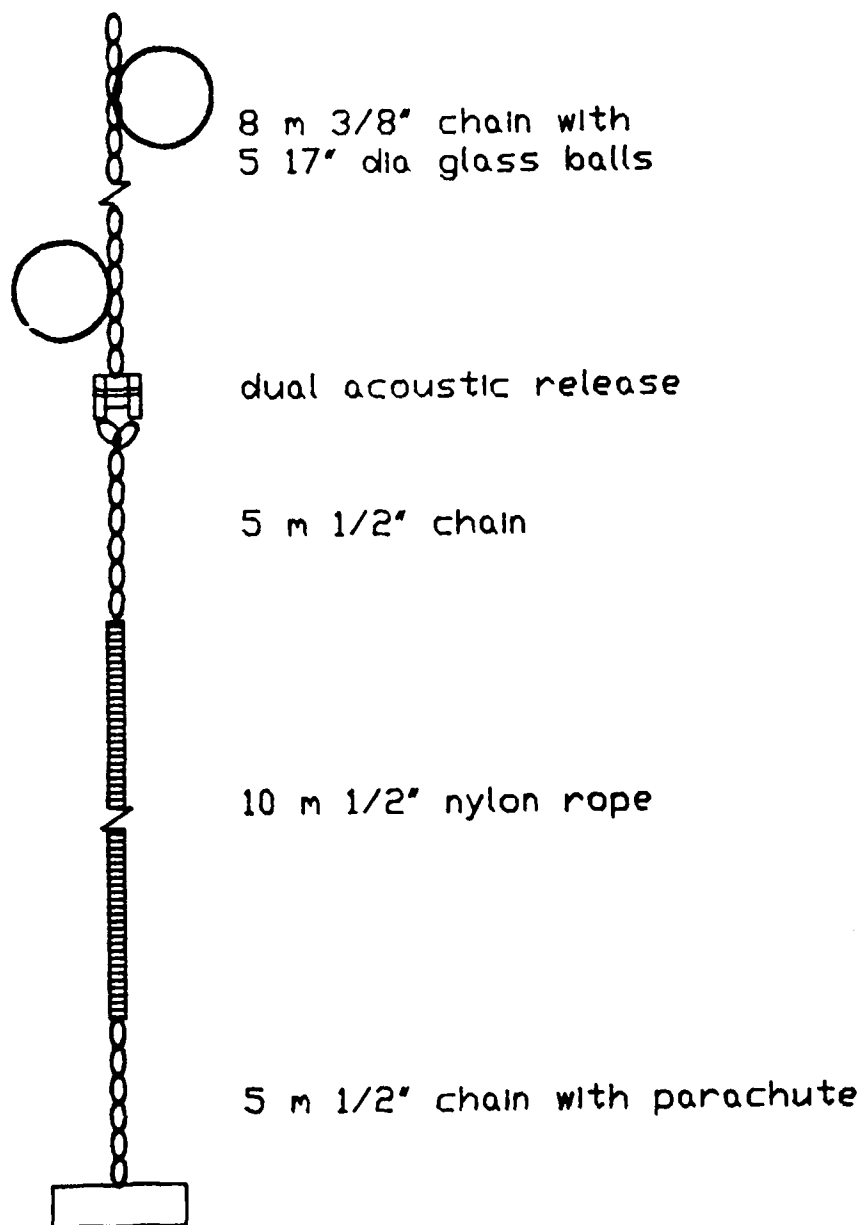
Figure 8: bottom-mooring-configuration-2(typical)

8 m 3/8" chain with
5 17" dia glass balls

dual acoustic release

5 m 1/2" chain

10 m 1/2" dia kevlar rope

20 m 1/2" dia nylon rope

5 m 1/2" chain with parachute
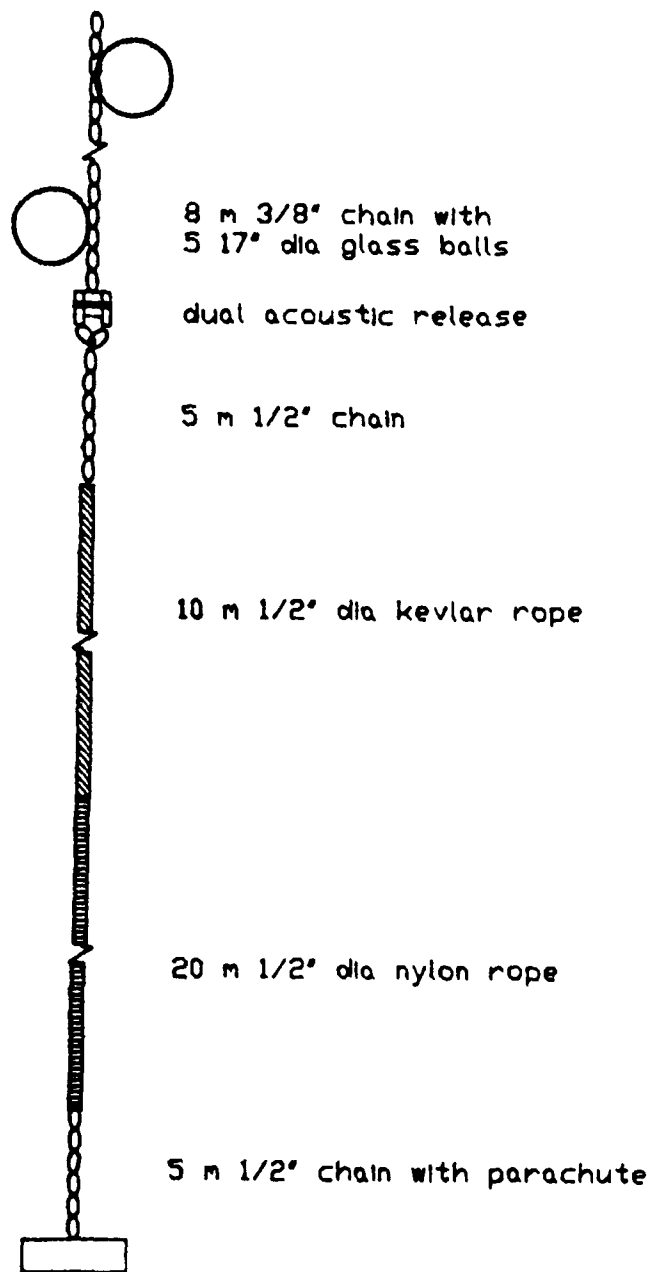
Figure 9: bottom-mooring-configuration-3(typical)

36' DIA SYNTACTIC FOAM SPHERE

1.0 M 1/2 INCH DIA CHAIN
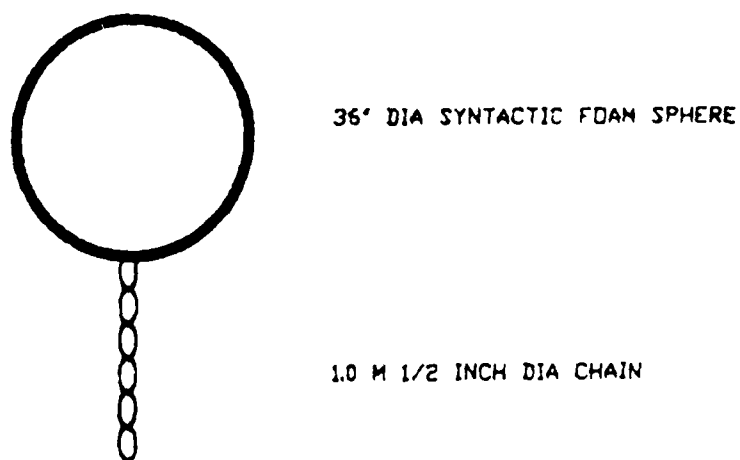
Figure 10: top configuration-1(typical)

36' DIA STEEL SPHERE

1.0 M 1/2 INCH DIA CHAIN

15.0 M KEVLAR ROPE
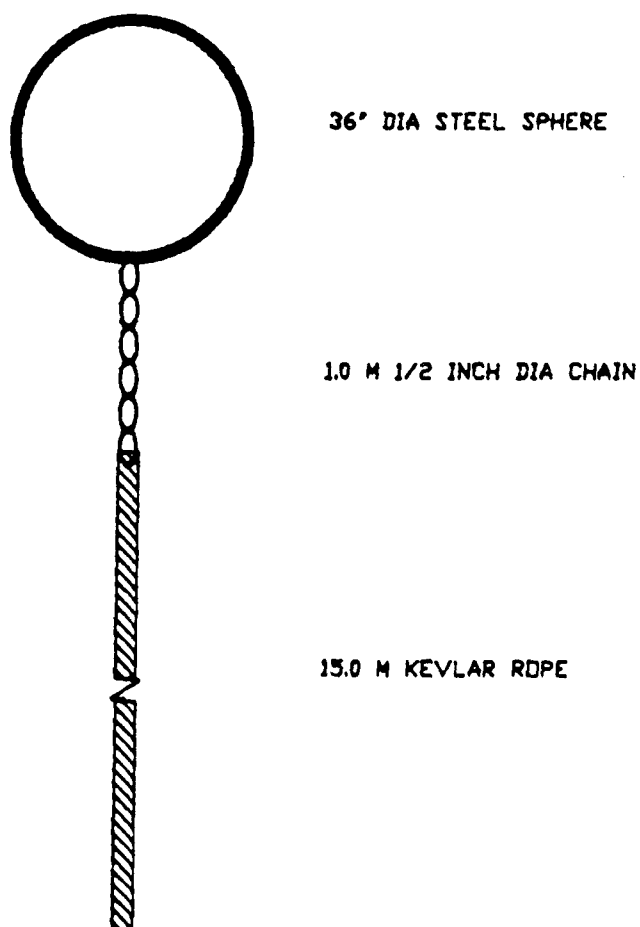
Figure 11: top configuration-2(typical)

2 NOS 17" DIA GLASS BALLS
WITH RECOVERY AIDS

3.0 M 1/2 INCH DIA CHAIN

15 M 1/2 INCH DIA POLYPROPYLINE ROPE

30 M 3/8" DIA CHAIN WITH
20 NOS 17" DIA GLASS BALLS

Figure 12: top configuration-3(typical)

2 17" dia glass balls
with recovery aids

3 m 1/2" chain

15 m 1/2" dia polypropyline rope

30 m 3/8" chain with
20 17" dia glass balls

10 m 1/2" dia kevlar rope

Figure 13: top configuration–4(typical)

6c. STEP-WISE REFINEMENT OF THE DESIGN

The third knowledge base is responsible for the development of the final design by the step-wise refinement of the rudimentary configuration. This is achieved by su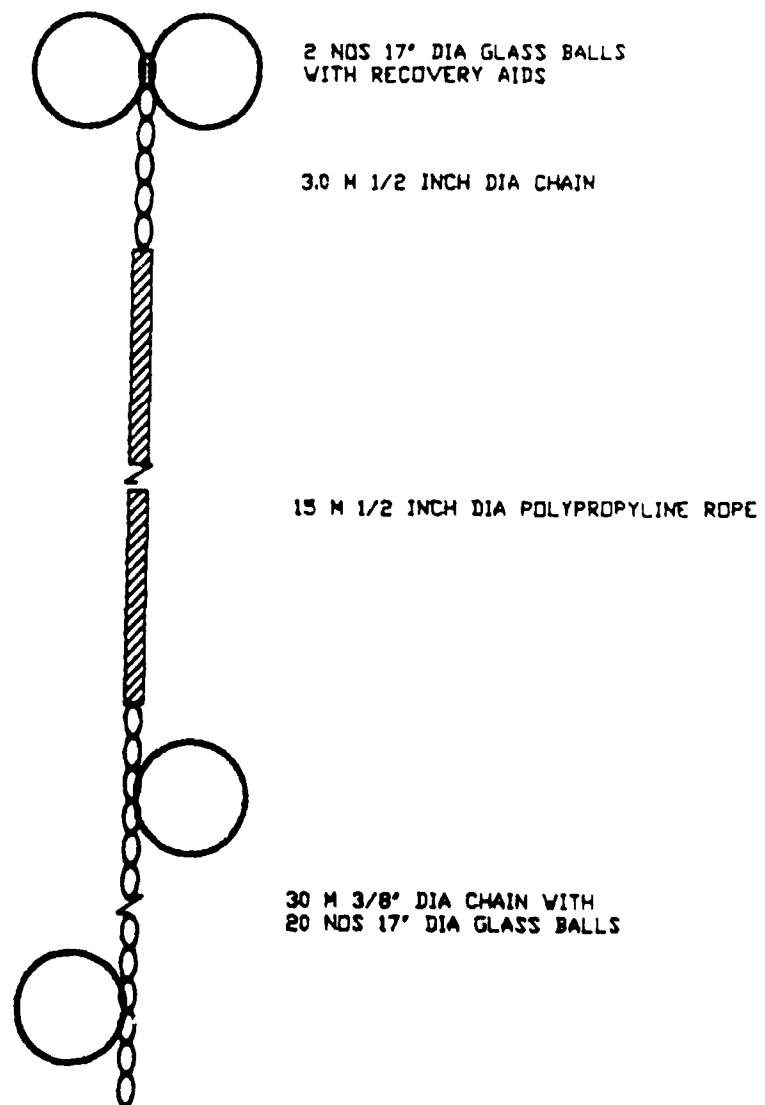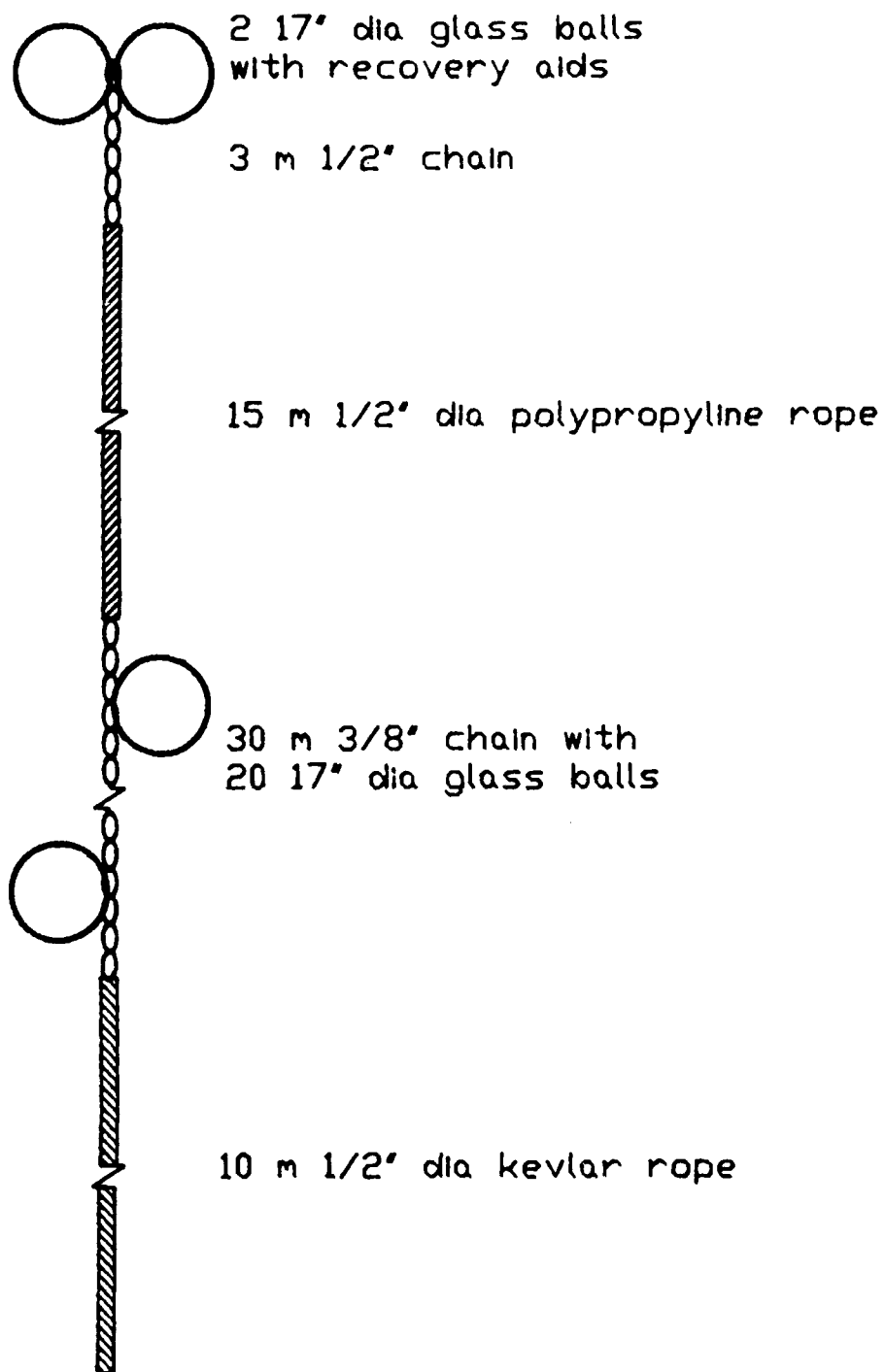bjecting the initial configuration to a series of analyses and modifying the configuration on the basis of the results obtained.

Static analysis, without taking into account the velocity, is done first to design the back-up buoyancy and just enough primary buoyancy for the mooring to stand up in a no current situation. Once the back-up buoyancy is designed, the distance between the sea-bottom and the acoustic release is known and the final bottom mooring configuration is selected accordingly.

Static analysis under the influence of the user specified velocity profile is done on the configuration updated after the no current analysis. Dip, excursion and tilt-angle at the instrument locations are found from the equilibrium position of the mooring. These values are checked for the restrictions imposed by the user. If it is found that the motion restrictions are violated, primary buoyancy is increased and a fresh analysis is done.

The increasing of primary buoyancy is worth exploring more in detail. When glass balls are being used for primary buoyancy, if this increase is effected by adding one glass ball at a time then the system performance will be affected adversely. Hence the system tries to predict the number of glass balls required to achieve the user specified motion restrictions at the instrument locations. To do this, first the

current analysis is done on the mooring configuration coming out of the no current analysis and the equilibrium configuration determined. Then a single glass ball is added to the primary buoyancy and the equilibrium position determined again. Based on these two positions, the response of the mooring to the addition of a single buoy is found out. Now the number of glass balls required to satisfy the restrictions is predicted by linear extrapolation. These glass balls are added to the primary buoyancy and the equilibrium position determined once again. If this configuration also does not satisfy the restrictions, then a fresh prediction is done using the last two equilibrium positions. This process continues till the motion restrictions are satisfied. The system makes sure that the number of glass balls added was indeed the minimum number required to achieve the specified restrictions. The maximum tension in all mooring components are found out and recorded.

Anchor design is done after the current analysis using the force vector acting on the anchor. Once the anchor size is determined using the formula given by Wood [1987], the launch analysis is invoked. Launch analysis will not modify the configuration . But the tension in every component is found out and if it exceeds the value recorded from the current analysis then this field in the component record is updated.

Figures 14 and 15 show the flow charts for the step-wise refinement of the design.

```
┌─────────────────────────────────────────────┐
│          design the back-up buoyancy          │
│     so that it is possible to retrieve       │
│        the instruments by activating          │
│         the acoustic release even if          │
│        the primary buoyancy is lost           │
│             due to a failure                  │
└─────────────────────────────────────────────┘

┌─────────────────────────────────────────────┐
│  provide just enough primary buoyancy         │
│  so that the mooring will stand upright       │
│           in a no current situation           │
└─────────────────────────────────────────────┘

        ┌─────────────────────────────┐
        │    update mooring files     │
        └─────────────────────────────┘
```
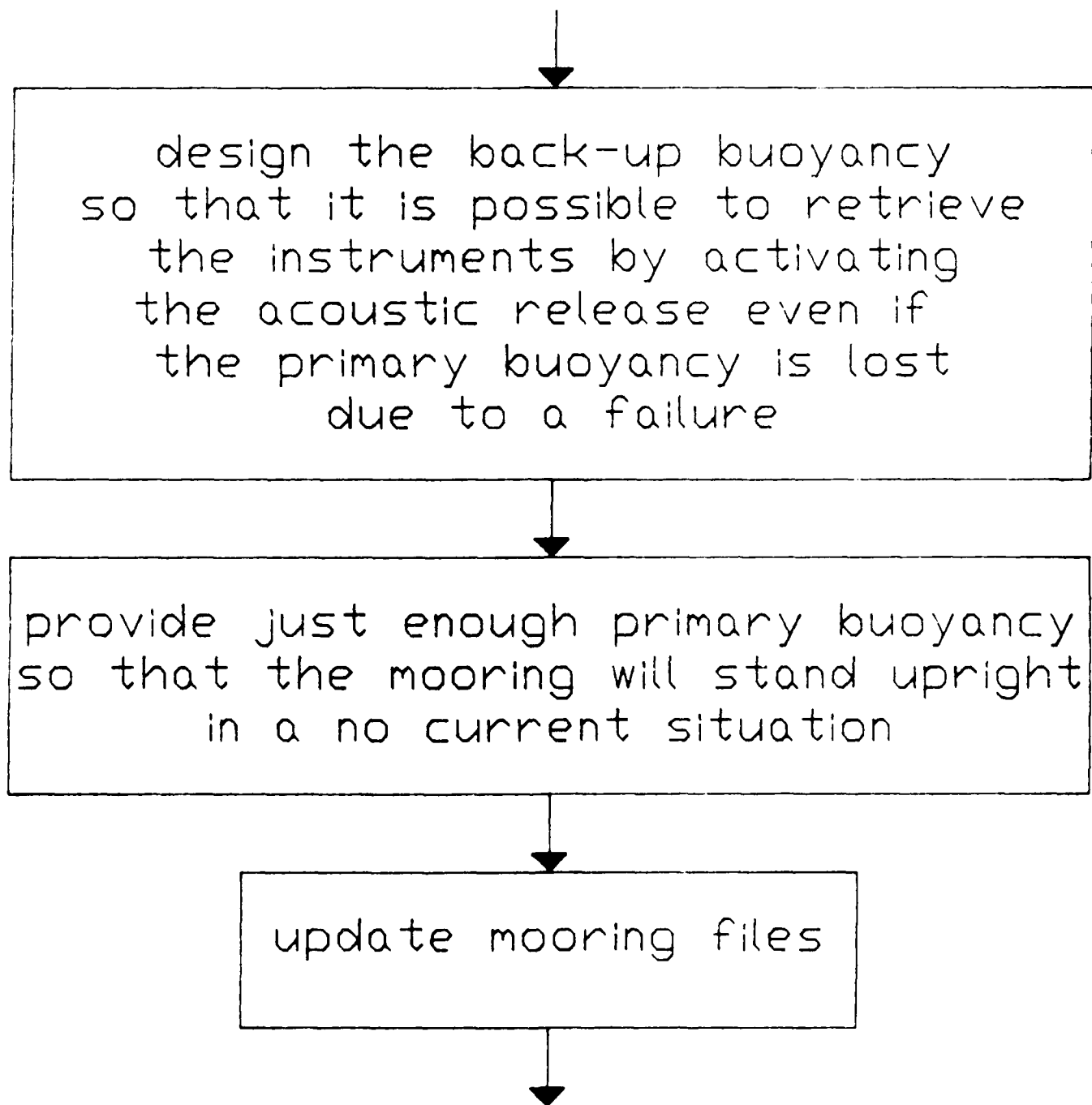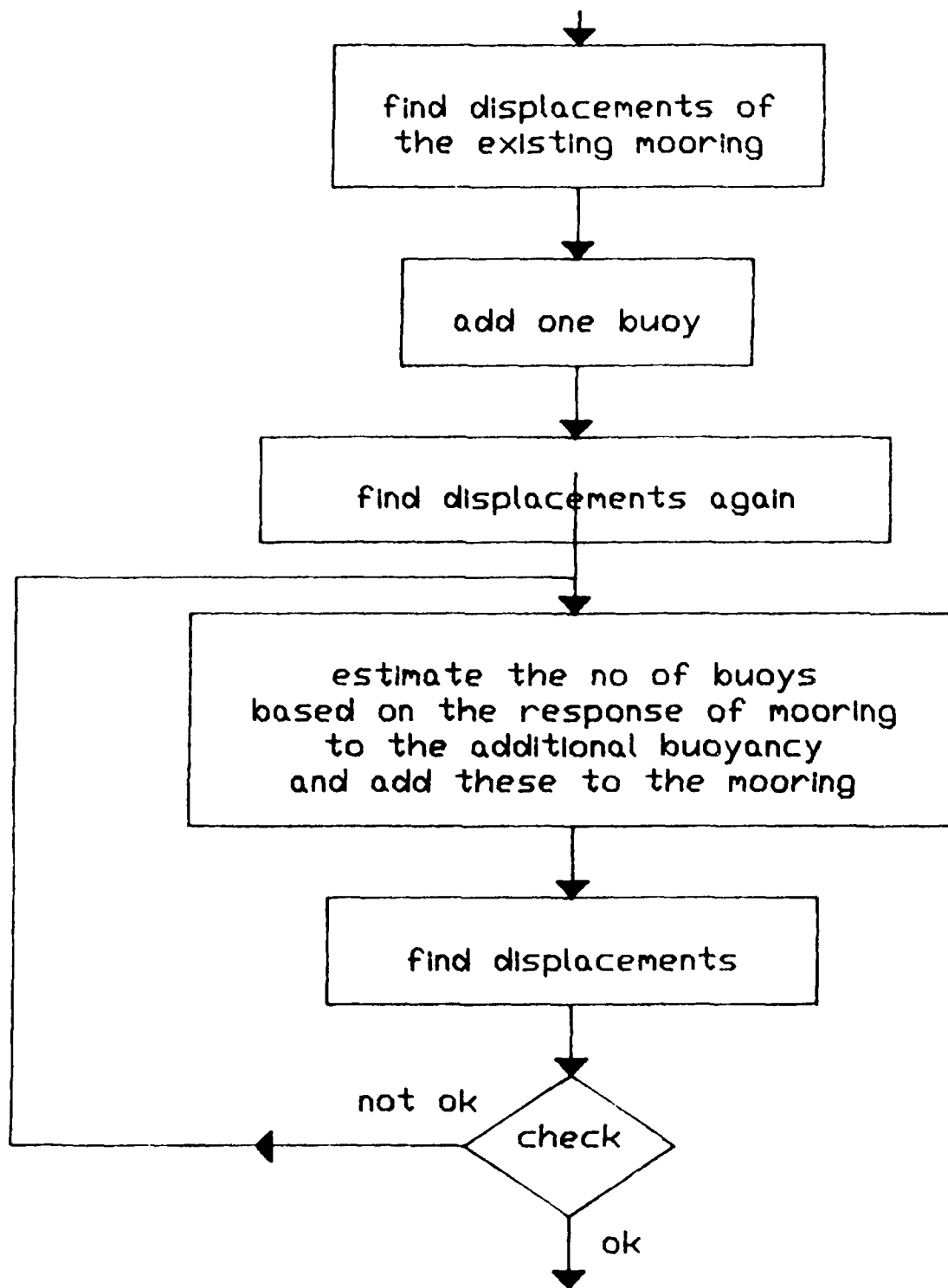
Figure 14: static no current analysis

Figure 15: current analysis

6d. CHECKING THE DESIGN

After completing a cycle of analyses, every mooring part is checked to see if the maximum tension recorded or the deployment depth are exceeding the allowable values. If this is the case then the data base ˙ searched for a suitable replacement. If a replacement is found then the configuration is changed to remove the failed item and replace it with the new item from the data base. Otherwise an error message is displayed identifying the problem. If a change is made then the analyses described in the last section are repeated again. This process goes on till a design is evolved which does not warrant any change after the tension and depth check.

To determine the allowable tension in a mooring component, a safety factor is applied to it's breaking strength. Factor of safety figures for various types of mooring components are coded into the program. Values for this implementation were obtained from the rules of thumb compiled in Wood [1987].

The items in the data base are sorted in the increasing order of the weight in air. To rank different types of the same mooring part in the order of preference, weight in air is a better criterion than cost. This is primarily because the operational costs associated with the deployment usually outrun the material costs. The total weight of the mooring is a significant factor in deciding the operational costs. Additionally, ranking based on weight in air eliminates constantly changing the data base to reflect new costs of items. Such changes are necessary only if the user desires a true cost of the mooring. When a particular type of mooring part

has to be chosen from the data base, the system always chooses the first suitable item for the initial configuration. If this item fails then the next suitable one is tried. This process ensures that the final design obtained is indeed the minimum weight design given a set of input data and a data base of mooring parts.

7. OUTPUT AND CAD UTILIZATION

There are two output options for the system. One is a text file describing the final design and the other is a plot of the final design using a CAD package.

For the plot option, the CAD package used is AUTOCAD. To make the CAD package transparent to the user, a software interface has been developed between the system and the CAD package.

By processing the two internal files, mooring component list and mooring accessory list, all information necessary to produce the drawing are collected. Using this information and a master drawing file, a text file describing the specific design is produced. A script file is prepared which contains the commands to invoke the plot routine of AUTOCAD. Then the CAD package is invoked with these two files passed as parameters. The result is the production of a drawing showing the final mooring configuration without any user interference.

The master drawing file contains the images of all 'building blocks' that are used for single point subsurface mooring design. The building blocks are specific drawing entities such as acoustic release, glass ball, anchor etc. These are created interactively using the CAD package in the conventional manner.

Conversion of binary output files, created by analysis programs, into a drawing file compatible with a CAD package is an important feature of this system. The software inteface between an expert system and a CAD package can be a very useful

feature in many applications.

8. CONCEPTS OF MACHINE LEARNING

The ability of the system to learn from it's experience is an important concept in artificial intelligence. To show that this is important for our system also, we will examine a specific decision making process in the second knowledge base. From the input data the system has to determine whether the mooring is in a strong current region or in a weak current region. But there is no easy way to decide if a particular set of input data corresponds to strong current region or not. The only solution is by trial and error, first trying the weak current option and if the design fails then going for the strong current configuration. If the system can remember the failure cases, then the ability of the system to make a decision will improve each time it encounters a failure.

To achieve this, the following data are written into a disc file whenever a design failure is encountered:

1. velocity profile;

2. motion restrictions;

3. distance from the sea-bottom to the top most instrument.

This disc file is referred to as the memory of the system. Whenever a fresh design has to be made, the system compares the input data with the failure records stored in it's memory. If there is at least one record in the memory which has :

(1) weaker velocity profile and

(2) less stringent motion restrictions and

(3) less distance from the sea-bottom to the top most instrument than the present input data and for which a strong current mooring resulted, then the situation is easily defined as the strong current region.

9. FAILURE HANDLING AND ERROR RECOVERY

It is important that the system should never come up with a flawed design, whatever the input data set might be. To achieve this, the intermediate results are checked for validity through out the design process. If an exception condition occurs, the system halts the design process and outputs an error message explaining the problem.

Two types of error conditions can occur in the design process:

1. A situation where a mooring can not be designed based on the input data.

2. A flaw within the system which prevents it from arriving at a design which, in fact, is possible.

Following are the error conditions belonging to the first category:

1. MOORING OUT OF RANGE IN NO CURRENT ANALYSIS.

This can occur if the lowermost instrument in the mooring is enough close to the sea–bottom such that it is not possible to provide enough back–up buoyancy.

2. MOORING OUT OF RANGE IN CURRENT ANALYSIS.

If the motion restrictions are too stringent, then the number of glass balls required will be enormously large and consequently the system tries a strong current configuration. But if it is impossible to achieve the motion restrictions using the flotation devices in the database even with a strong current configuration then the system halts the design process and displays the above error message.

3. TENSION OR DEPTH EXCEEDS IN *component name.*

If the allowable values of tension or depth are exceeded in a mooring component and there are no suitable replacements in the database and the present configuration is the one corresponding to the weak current region, then the strong current configuration is adopted and the analyses are repeated again. But if this error condition occured while the program was working with the strong current configuration, then the system displays the above error message and halts execution.

Errors of the second category can occur due to a corrupted database, a missing file or even an undetected bug in the program. An effort has been made to detect such error conditions by checking the variable values and ensuring that they are in the expected range. Such checks are done frequently through out the design process and if an error is detected, the system displays the module in which the error occured and the nature of the error. Then it halts the execution. Based on the information displayed, the knowledge engineer will be able to detect and rectify the problem.

10. VALIDATION OF THE SYSTEM

The testing of a computer system deserves as much attention as it's development. Rigorous testing is the only way to ascertain that the system is bug–free. Some of the results from the testing process are documented in this section. The configurations generated by the expert system are checked for correctness using the classifications and rules of thumb given in Wood [1987].

Example 1:

Array description	:5 hydrophones spaced at 25m;
Array location	:Lowest instrument at 100m from the sea–bottom;
Velocity profile	:Uniform velocity at 50 cm/sec;
Motion restrictions	
Dip	:5m;
Excursion	:15m;
Waterdepth	:1000m;
Deployment location	
Latitude	:50°N;
Longitude	:50°E;

Figure 16 shows the design generated by the expert system.

The system first tried the weak current configuration, realized that it is not possible to satisfy the motion restrictions and then designed the mooring using the

strong current configuration. It searched through the data base and picked up the suitable components. Since it is an acoustic array, electro-mechanic cable is used in the middle configuration. Syntactic foam sphere is used for primary buoyancy since the top most instrument is located lower than the steel–sphere crush depth. Since the deployment location is outside the fish–bite zone, kevlar is used instead of steel wire rope.

Example 2:

Array description	:4 current meters spaced at 50m;
Array location	:Lowest instrument at 50m from the sea–bottom;
Velocity profile	:Uniform velocity at 25 cm/sec;
Motion restrictions	
Dip	:5m;
Excursion	:10m;
Tilt angle	:15°;
Waterdepth	:2000m;
Deployment location	
Latitude	:30°N;
Longitude	:30°E;

Figure 17 shows the design generated by the expert system.

In this case, glass balls are provided for primary buoyancy since the input

conditions correspond to a weak current region. Since the deployment location is inside the fish bite zone, wire rope is used in the middle. Presence of Nylon at the bottom and recovery aids at the top elucidates that the inference mechanisms of the knowledge base are working properly.

Example 3:

Array description	:5 hydrophones spaced at 20m;
Array location	:Lowest instrument at 360m from the sea–bottom;
Velocity profile	:Uniform velocity at 20 cm/sec;
Motion restrictions	
Dip	:2m;
Excursion	:20m;
Waterdepth	:500m;
Deployment location	
Latitude	:50°N;
Longitude	:30°E;

Figure 18 shows the design generated by the expert system.

As the top experiment depth in this case is only 60m, steel sphere is used as primary buoyancy. Kevlar is used in the top and bottom configurations since the mooring is outside the fish bite zone. Since Kevlar is almost neutrally buoyant, only 3 glass balls are required for back-up buoyancy.

1 nos SYNTACTIC FOAM SPHERE #3

1.0 m 3/8 INCH DIA CHAIN

15.0 m 1/2 INCH DIA KEVLAR ROPE

104.0 m 16-PR KEV ELECTRO-MECHANIC CABLE

6.5 m 3/8 INCH DIA CHAIN with
4 nos 17 INCH DIA GLASS BALLS

DUAL ACOUSTIC RELEASE

5.0 m 3/8 INCH DIA CHAIN

70.0 m 1/2 INCH DIA KEVLAR ROPE

10.0 m 1.5 INCH DIA NYLON ROPE

5.0 m 3/8 INCH DIA CHAIN with parachute

clump anchor: weight = 1204.4 kilograms

Figure 16: example 1

2 nos 17 INCH DIA GLASS BALLS
with recovery aids

3.0 m 3/8 INCH DIA CHAIN

15.0 m 1/2 INCH DIA POLYPROPYLINE ROPE

54.5 m 3/8 INCH DIA CHAIN with
36 nos 17 INCH DIA GLASS BALLS

164.0 m WIRE ROPE #1

17.0 m 3/8 INCH DIA CHAIN with
11 nos 17 INCH DIA GLASS BALLS

DUAL ACOUSTIC RELEASE

5.0 m 3/8 INCH DIA CHAIN

19.5 m 1.5 INCH DIA NYLON ROPE

5.0 m 3/8 INCH DIA CHAIN with parachute

clump anchor: weight = 1078.6 kilograms

Figure 17: example 2

1 nos STEEL SPHERE #2

1.0 m 3/8 INCH DIA CHAIN

15.0 m 3/8 INCH DIA KEVLAR ROPE

84.0 m KEV ELECTRO-MECHANIC CABLE 1

5.0 m 3/8 INCH DIA CHAIN with
3 nos 17 INCH DIA GLASS BALLS

DUAL ACOUSTIC RELEASE

5.0 m 3/8 INCH DIA CHAIN

331.5 m 3/8 INCH DIA KEVLAR ROPE

10.0 m 1.5 INCH DIA NYLON ROPE

5.0 m 3/8 INCH DIA CHAIN with parachute
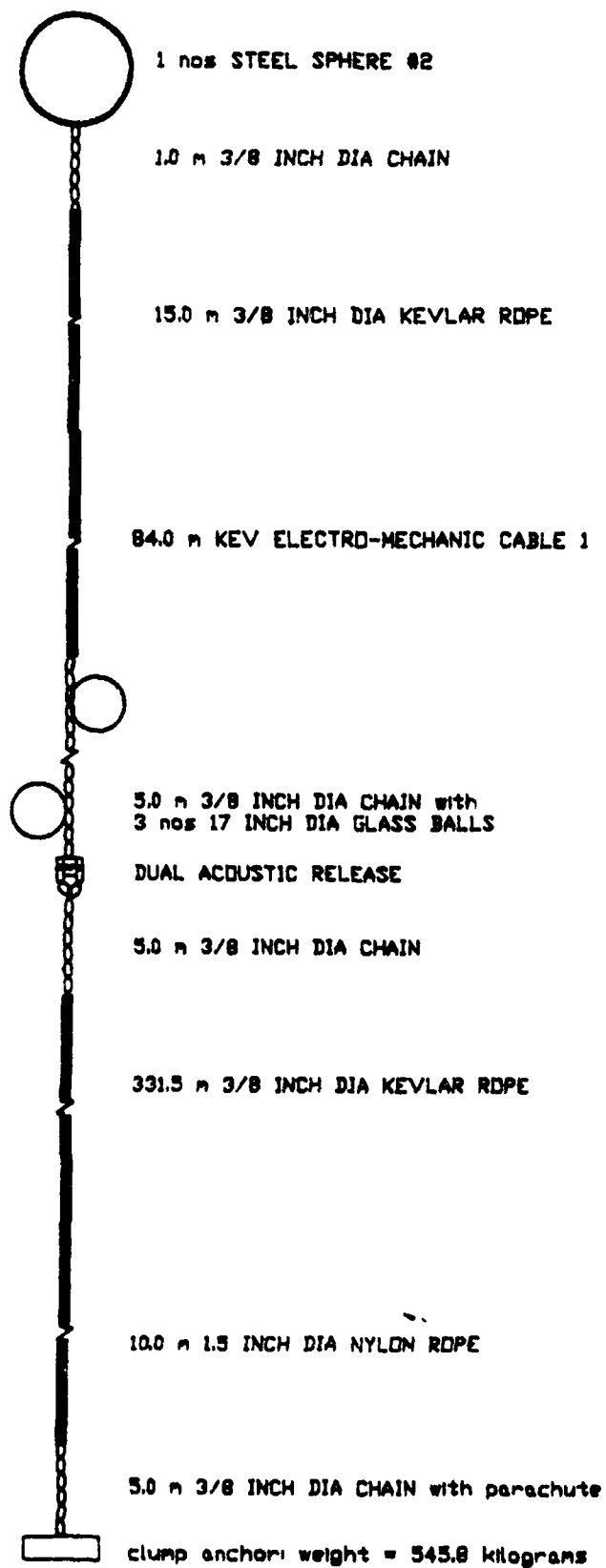
clump anchor: weight = 545.8 kilograms

Figure 18: example 3

11. CONCLUSION

An expert/cad system is developed and implemented on an IBM PC/AT for subsurface mooring design. It has a user-friendly, interactive, menu-driven input procedure and a sophisticated output facility. The design process is totally automated and the requirement to consult a human expert is eliminated. A laborious exercise which is typically completed in a time span of the order of months can now be done in a few minutes using the expert system. The system has tremendous flexibility and a knowledge engineer can easily adapt it to the specific requirements of a particular user. The concept of machine learning, which is introduced by recording the failure data and using this information in the later decision making processes, can be developed in future to streamline the performance of the system.

REFERENCES

BERTEAUX, H.O. (1976): Buoy Engineering. John Wiley and Sons, New York.

DAS, M.L. (1986): Knowledge base for structural design. Proceedings of 1st International Conference on Applications of Artificial Intelligence in Engineering Problems, V.1, 33–43. Southhampton University, U.K.

HEINMILLER, R.H. (1976): Mooring Operation Techniques of the Buoy Project at the Woods Hole Oceanographic Institute. WHOI Report 76–69, Woods Hole Oceanographic Institute, Woods Hole, MA.

INSIGHT 2+ Reference manual (1986). Level Five Research, Inc.

SKOP, R.A., (1988): Mooring Systems — a state of the art review. Journal of Offshore and Arctic Engineering, ASME (in press).

SKOP, R.A., & MARK, J.(1973): A Fortran IV program for computing the static deflections of structural cable arrays. NRL Report 7640, Naval Research Laboratory, Washington, D.C.

WOOD, S.L. (1987): Architecture of an Expert System for oceanographic mooring design. MS Thesis, University of Miami, Miami, Fl.