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A Wide Variety of Computer Appearance

Des nombreuses possibilités d'utilisation de l'ordinateur

Die vielen Anwendungsmöglichkeiten des Computers

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Summary

This paper deals with the computer use for the design and engineering of the Dunlin A gravity type production and storage platform 156 m deep North Sea waters. After explaining the platform concept and functions, this paper deals with the different applications as could be distinguished. Computer aided dimensioning and parameter studies, computerrun simulation, computer control and administration of the design and engineering process and the pure structural FEM analysis for the platform caisson base and the dynamic frame analysis for the platform towers and deck are explained and illustrated.

Résumé

Cet article présente l' utilisation de l'ordinateur lors du projet et de la conception de la plateforme de production et de stockage, de type gravitaire Dunlin A, réalisée sur des fonds de la Mer du Nord, à 156 m. La concéption et le fonctionnement de la plateforme sont expliqués, de même que diverses applications possibles. Le dimensionnement à l'aide de l' ordinateur, les études de paramètres, la simulation à l' aide de l' ordinateur, le contrôle et l'administration du projet d' engineering, l' analyse purement structurale au moyen des éléments finis de la base en caissons de la plateforme, et l' analyse dynamique des tours et du pont de la plateforma font l'objet de cet article.

Zusammenfassung

Der Artikel behandelt die Anwendung des Computers für die Planung und den Entwurf eines Produktion - und Lager-Platforms des Gravitätstyps, Dunlin A, im Nordmeer bei 156 m Tiefe. Die Planung und Funktionen des Platforms werden erklärt, sowie die verschiedenen Anwendungsmöglichkeiten. Computergestütze Bemessungen und Parameterstudien, Computer-Simulierung, - Ueberwachung und - Verwaltung des Entwurfs und Planungsverfahrens wowie die anhand von finiten Elementen durchgeführte reine Berechnung des Platformcaissons und die dynamische durchgeführte reine Berechnung des Platformcaissons und die dynamische Berechnung der Platformtürme und - Brücke werden erklärt und illustriert.

1. INTRODUCTION.

The 1973 oil-crisis caused an acceleration in the construction of oilproductionfacilities in the Northern North Sea. Several factors including the boom in steelconstruction causing a scarcity in steelworkconstruction capacity favoured the development, design and construction of fourteen concrete gravity type platforms.

The Dunlin A, production and storage platform designed and constructed by an Anglo-Dutch consortium "ANDOC" for Shell Expro, is one of these platforms.

This paper will deal with the computerwork used for design and engineering of this simultaneously designed and constructed, US $ 300 millions worth, job.
After a brief description of the platform, it's functions and the way it is constructed, the different types of computer usage to distinguish are described in their function for the design and engineering process. They are the administration and control functions, the parameter studies, the dimensioning applications, the simulating exercises and last but not least, the bulky structural analysis which can be basically divided into the shell analysis for the base and the frame analysis for deck and columns.

2. THE DUNLIN PLATFORM.

2.1 It's functions.

The Dunlin platform serves for the production of about 200.000 barrels of crude oil per day in 156 m deep water of the Northern North Sea. This required a working platform of over 4.500 sq.m. to support the necessary equipment. This includes the drilling rig and support units for the 48 wells to be drilled from the platform, living accomodation for 150 people, heli-deck, flare boom hoisting equipment, heat exchangers to cool the produced oil before storage, a gasturbine for the platform energy consumption etc. The wet weight of all this equipment amounts to a 20.000 tonnes in total. The unit is further capable of storing a 1 million barrels of crude in the base as buffer storage for waterseparation.

2.2 How it looks like. (See figure 1)

The platformdeck consists of a 85 x 65 m grid of 6 m high boxgirders. This deck supports the facilities housed in modules on top of it and serves further as part of a space frame consisting of the four columns and this deck.
The 143 m high columns built up from 113 m corical concrete towers and a 30 m steeltop do in the first place support the deck on a safe height of 23 m above the sea. These columns further have to resist the horizontal forces from waves and wind, where they act as a space frame with the deck. In between two of the columns three tubular girder bracings are spanning to guide and support the conductors against lateral loads by waves, current and wind.
The columns do contain further the equipment to control and operate the storage function of the platform and a lot of piperuns. During certain constructionstages the volume of the columns is used as the stabilizing floatation capacity.

The 100 x 100 m wide and 32 m high caisson is built up of rectangular cells of 11 x 11 m. It has arched outer walls, a cassinishell type roof and a ribstrengthened bottom. The caisson forms the basic floatation body for horizontal and vertical transport, it will function as the storage reservoir for crude, it provides the foundationplane, and by it's own weight together with the added solid ballast it provides the stability during towing and after final installation on the seabed.
Underneath the caissonbottom 4 m long steel H-beam shaped skirts are penetrating in the seabed, serving mainly for the transfer of horizontal forces to deeper soillayers and to protect the foundation strata against scouring.

2.3 How it was constructed.

After a 6 week tenderperiod and another 6 weeks of negotiations Andoc was awarded the design and construct contract of the Dunlin A platform on the 1st May 1974. The first pours of concrete took place 4 months later in the graving dock on the "Maasvlakte", a reclaimed area close to the Rotterdam harbour entrance.
Sheetpile wall strenghtened trenches in the graving dock bottom were provided to house the skirts.

After completion of the 80 cm thick slab, the 4 m high ribs, 4 m height of the walls and just 4 m extra height of the outer walls (functioning as splashboard), the 4.80 m heigh "saucer" of 100 x 100 m square was floated up in the flooded dry dock with the aid of an aircushion in between the skirts to reduce the draft. This happened in the beginning of June 1975. Another year of construction in the Rotterdam harbour area followed. Whilst floating in 22 m deep water the caisson walls and concrete towers were slipformed and all the other concrete works were completed.
In June 1976 the structure was towed to a Norwegian fjord. Here solid ballast was placed in the caisson and after completion of all the installation facilities the platform was immersed to place the 30 m high steel columns on top of the towers. The deck was installed by floating it on a barge above the submerged platform from which only the top 8 m of the columns, were above the water. After the necessary hook up the platform was towed to it's installationsite in the North Sea, early June 1977, only 3 years after design and construction started.

3. COMPUTER AIDED DIMENSIONING.

It was new and complex. This required two types of computer usage that are usually not distinguished as a purpose in itself for designers. The first one was the parameter study as used for overcoming the problem of quantitatively unknown physical phenomena and the other was the aid of the computer for optimizing dimensions. Chapter 4 will deal with parameter studies as used.
Most of the many functions of the different components of the platform are interactive as may be clear from the description in chapter 2.2. Especially characteristics, such as draft, stability, payload, membrame strength from columns and platform have a linear relationship to main dimensions such as caissonwidth, caissonheight, columndiametre, centre to centre distance of columns and solid ballast inserted in the caisson.
It has proved to be very useful to develop a computerprogram with such relations built in. Providing some of the basic dimensions or series of basic dimensions, the other basic dimensions were calculated in view of pre-set boundary conditions for draft, freeboard after inserting solid ballast, minimum meta centre height during caisson roof immersion, minimum meta centre height during tow with full payload on deck, minimum storage capacity.

It was possible to get a good impression of the range of optimum caisson-dimensions in a few computerruns. This impression was based firstly on the selection of series of platformdimensions that fullfill the pre-set boundary conditions and secondly on the total quantities of concrete and solid ballast incorporated in the selected platforms that become available as output simultaneously.
Further fast straight forward computer evaluation of the lateral forces and overturning moments caused by waveforces and foundation resistance were used as a basis for the platform selected for further evaluation.
To start with, this was basically an electronic pocketcalculator handcheck of all the assumed characteristics by an experienced designer!

All with all a useful pragmatic computer exercise to increase the understanding of the behaviour and characteristics of the project we were designing.
Before the actual program and basic design concept of a platform was made, some detail studies for dimensioning were carried out with the aid of standard programs. For instance the amount of load that was transferred by the caisson internal walls to roof and bottom had to be known before considering the reduction of wall thickness towards the caisson central part (figure 2). Just with some computerruns of a disc program in which different caisson heights and reductions of wallthickness from the outside towards the centre were inserted, simple design graphs were developped.

4. PARAMETER STUDIES.

The dimensioning studies with standard and purpose-written programs were in fact trial and error methods to enable us to select the optimum solution in an unknown field. Parameter studies however, normally used in the same trial and error way, were basically encouraged to proof that some characteristic being unknown was not important for the design. In case the unknown characteristic proved to be really important, the design had to be adapted to the highest possible level one could imagine.
For example the whole field of damping was extremely important for the response of the structure to dynamicloads with a period close to the platforms own period. Damping forces from the foundation strata generated in rocking and sliding modes of the platform, on which hardly any information existed,proved to be of great influence on the internal loaddistribution.

The same applied for the material damping values of concrete and steel and hydrodynamic damping of water around the platform legs. As different sets of values produced extremes on different places in deck and columns, one can imagine that a very elaborate parameter study had to follow to find these extremes.

Parameter studies in the sence as defined were also quite often performed in order to establish the effect of a certain magnitude of tolerances in the dimensions. Results were often encouraging, hence facilitating survey and inspection work.

5. ADMINISTRATION AND CONTROL.

Although this chapter may apparently got lost in this context, the purpose of it is that it presents a very useful field of computerapplications for the designer and the structural engineer in case they are working on something big fast and complex as the subject described here.

Fifteen years ago, a designer used to have a mechanic calculating machine of very limited capacity and performance according to our present day view, but being more expensive than a small car. In those days the investment for one item of output were considerable.

Nowadays a small electronic pocket calculator, being much faster and more versatile than the machine mentioned above is cheaper than one working hour of our designer. We now have a situation that the costs per item of output are neglible and that the designer, in a moment of recklessness can approach the computer in such a way that he gets more output than he can ever digest during the rest of his life.

It is this phenomena that forced us to promote a most conscious computeruse during the design of the Dunlin platform. In certain cases we selected a physical laboratory tests instead of a computersimulation, for instance for the detailed analysis of the deck to column joints. Instead of an elaborate finite element run for which "only a few elements for stiffened panels" still had to be developped a perspex scale model was used. Our observation that computeroriented engineers always are to optimistic in time and consequentially in costs was the basis of that decision, although the estimates for a finite elementrun and a perspex scale model were about the same.

A wide variety of computerprograms for administration and control of the job was written and used. This was inspired both by the magnitude and the complexity of the job.
We developped two extremely useful programs "TEHREG" and "CALREG" for the administration of drawings and calculations. Distributions, requests for approvals, approvals themselves, revisions and the dates of all of these actions from all calculationpapers and drawings were fed into the computer through these programs. We could not have done without it. One should realize that over 15 subcontractors worked on the design, that had to be by the client with his consultants in the U.K. and the certifying authority D.N.V. in Norway.

In chapter 3 we mentioned the activity of calculating the stability of the platform. During the actual detailed design and construction, with it's many changes, a daily "bookkeeping" program "CASTA" for the dimensions, and distribution of weights was activated.
The programs output presented the stability heel during preset wind and draft conditions including the safety and the meta centric height.

Another exercise in this category, although not consequentially used for various reasons, was the computercontrol of the operating manuals including their updates, and internal references. The lack of sufficient staff experience in this type of work against the required speed aborted this exercise.

6. SIMULATION EXERCISES.

Beside the trial and error exercises encountered during dimensioning and parameter studies, simulation has been done by means of digital computer-programs to check if certain designed operations were correct, but especially to help the imagination of the crew who had to perform such operations and to train them consequentially.

The different towing stages, from Rotterdam harbour into the North Sea, the tow through the Norwegian fjords with the fully loaded 450.000 dwt platform and the final approach in wave and current of the installationsite in the North Sea were simulated on the computer of the Netherland Shipbuilding Research Station at Wageningen.

Not only the final arrangement and layout of the 8 tugs of 80.000 hp's all together around the platform was designed in this way but even the selection of the final operating crew was decided by means of this provision.
Another area of careful simulation to check the envisaged procedure, was the ballast and leveling system to control vertical motions of the platform during immersion. One should realize that all pairs of cells could be individually ballasted, but that overloading of seperating walls between cells by differential waterlevels in adjacent cellpairs could lead to disastrous damage. This simulation exercise, which included the full ballast system with valves, pipes and cells, proved itself extremely useful for simulating emergency procedures that had to be selected by malfunctioning equipment and monotoring instruments. By careful use of this simulating program we were able to estimate better maximum loadings that could occur during operations governing the structural integrity.

7. THE SHELL AND DISC ANALYSIS.

7.1 Introduction.

The analysis of the caisson and concrete towers was mainly a job of straight forward finite element analysis.
The main problem areas here were:

- the selection of subdivision of the platform and of the proper steps from a course mesh to a fine mesh in subsequent runs.
- the proper analysis of differential temperature loading caused by partly stored hot oil inside the caisson.
- the nonlinearity of certain loadcases due to heavy membrane loading by hydrostatic pressure together with the effect of creep and construction tolerances in the dimensions.

7.2 Mesh selection.

From the start on, subdivision for FEM-analysis was selected with total units as small as possible. The base was considered infinitely stiff for the towerframe analysis as well as for the interaction of the soil with the caissonbottom. Such interactions were only evaluated in the detail-analysis of for instance towerwall embedment in the caissonroof.

As most important loadcases on the caisson are symmetrical, the basic start of all FEM-analyses was performed on a 1/8 section of the caisson (figure 3). With other, easier to use programs, using boundary conditions from the first run more detailed stress distributions were investigated. Asymmetrical loads, due to wave action and the consequential transfer from column forces into the base had to be investigated in more detail after high shear forces were found on certain places. These runs were also used for the global effect of asymmetrical temperature loading caused by only partial storage of hot oil.
In figure 4 a diagram is given, showing the different FEM-computerruns with their purpose.
The lesson we learned was that the idea of runs of limited size going from a coarse overall mesh to a fine local mesh was good. We however, learned as well that a careful planning, right from the first run onwards, considering the maximum versatility for detail runs in later stages is extremely important. Direct modelling in such a way that part of the final model can also be used for construction stages to be analysed proved to be very useful. In such an early planning the selection of the computerprogram(s) to be used with their specific features, such as accessibility, graphic display, in house experience, level of support, costs, capacity and all type of other characteristics play an important role.

7.3 Temperature loading.

As the caissonroof was a cassini type shell structure with wallthicknesses that varied from 2.5 m to 0.80 m being obviously loaded under certain temperature conditions with compression stresses on the inside up to tensile stresses far over the tensile strength of the concrete on the outside, one can imagine that no straight forward FEM-analysis could be made. Also special programs, dealing with cracked concrete could not be used as the temperature forced cracks, results in a not fully developped crack pattern as with bending.

With different approaches it was checked that no resulting membrane tension occurred in the roof and to abandon the possible damage by uncontrolled cracks the reinforcement was galvanized.

7.4 Non-linearity.

In many places the elastic stability of the shells and discs loaded with high compression pressures had to be checked. This was especially important for loadcases during immersion of the platform. As creep plays an important role in such cases, where initial tolerances causing prime deformations have to be assumed, load history curves had to be evaluated. Special computerprograms were written to perform this work as the evaluation could have to be very fast in case certain modifications on the load history dictated by the envisaged operationprogram had to be absorbed.

In one occasion, at the bottompart of the concrete towers, the tolerances were very critical. Twice a day the presently performed towercross-section-shape was loaded into a computerprogram. This program first evaluated the circularshape closest to the real cross-section and than checked the occuring moments incorporating creep effects.
From this the actual safely factor against buckling performed was calculated and checked with the requirements.

FRAME ANALYSIS.

The internal face distribution in the superstructure (= the portalframe) has been calculated using a 3D finite element computer simulation and the STRUDL program package. The columns and deck have been modelled as a spaceframe where the caisson is thought to be a stiff, rigid foundation. During the course of the project significant progress has been made in analysis techniques, especially where dynamics and fatigue are concerned. Looking back now, the frame analysis can be divided in three subsequent stages, the static part remaining basically unchanged and the dynamic part keeping up with the developping state of the art and the growing capabilities of the computer software.

Stage I: Static and quasi static analysis.

Once the structure has been modelled using adequate elements and element connections, the main effort consisted of the definition of loading cases. The dynamic character of the waveloadings has been simulated by applying a dynamic load factor on a static loading which is calculated for a number of "frozen" wavepositions.
The number of loading combinations for such a type of analysis is enormous. The following loading conditions are considered:

selfweight	1 condition
dead load	3 conditions
life load	7 conditions
wave heights/periods	10 conditions
wave directions	5 conditions
wave positions	10 conditions
analysis conditions	4 conditions

The number of loading combinations becomes:

$$1 \times 3 \times 7 \times 10 \times 5 \times 10 \times 4 = 42.000.$$

Using a 300 element frame model and requiring 2 fines of output per element this results in 300 x 2 x 42.000 = 25.200.000 lines of output. Physically this means 504.000 pages which, printed on normal paper, gives a stack with a height of 25 m!
Of course this has been reduced by some handcalculations and engineering feeling.

A number of 600 loading combinations have been analysed.
The computer, although it has calculated more loading cases and checked more types of structures than any of our engineers, still missed the capability of performing this significant step.

Stage II: 2D dynamic response analysis.

The use of dynamic loadfactors to simulate the dynamic character of the waveloadings was not appropriate. It appeared that the effect of dynamic amplification of the response was different for several parts of the structure, so a multi degree of freedom dynamic response calculation was required. This has been realized by using a 50 degrees of freedom lumped mass finite element idealization.
Using this model response analyses have been carried out for four wave periods.

For these waves the time histories of the loadings were calculated for each submerged joint of the structure, which in turn were used as loading input for the transient response calculation.
According to this analysis the waves near the resonance period (4.2 sec.) procedure severe stresses in the deck column connection, these stresses being of course very dependent on the dused damping.
The dominating influence of the damping and the resonance waves in a fatigue calculation, made this type of analysis insufficient for realistic lifetime predictions.
Because of the nature of the oceanographic data and the strong influence of resonance waves, a 3D frequency domain fatigue analysis had to be the basis for a trustworthy lifetime calculation.

Stage III: 3D spectral analysis. (figure 5)

The necessary software has been developped to enable us to carry out a full 3D probabilistic analysis.
The problems which we encountered during this development had to do with the transfer of a known study room theory to a fully operational and usable stage.
Theoretical problems concerning non-linearities and wavestatistics had to be solved and the resulting calculation methods implemented in the STRUDL program.

Also organisational aspects had to be looked at to avoid exceptional cpu-time usage and input preparation. This had been achieved by writing preprocessors which generate direct loading input and by using the harmonic response calculation technique for a considerable part of the frequency band. The results gave great confidence in the wed method and showed a more realistic dependency on parameters like natural period and damping.

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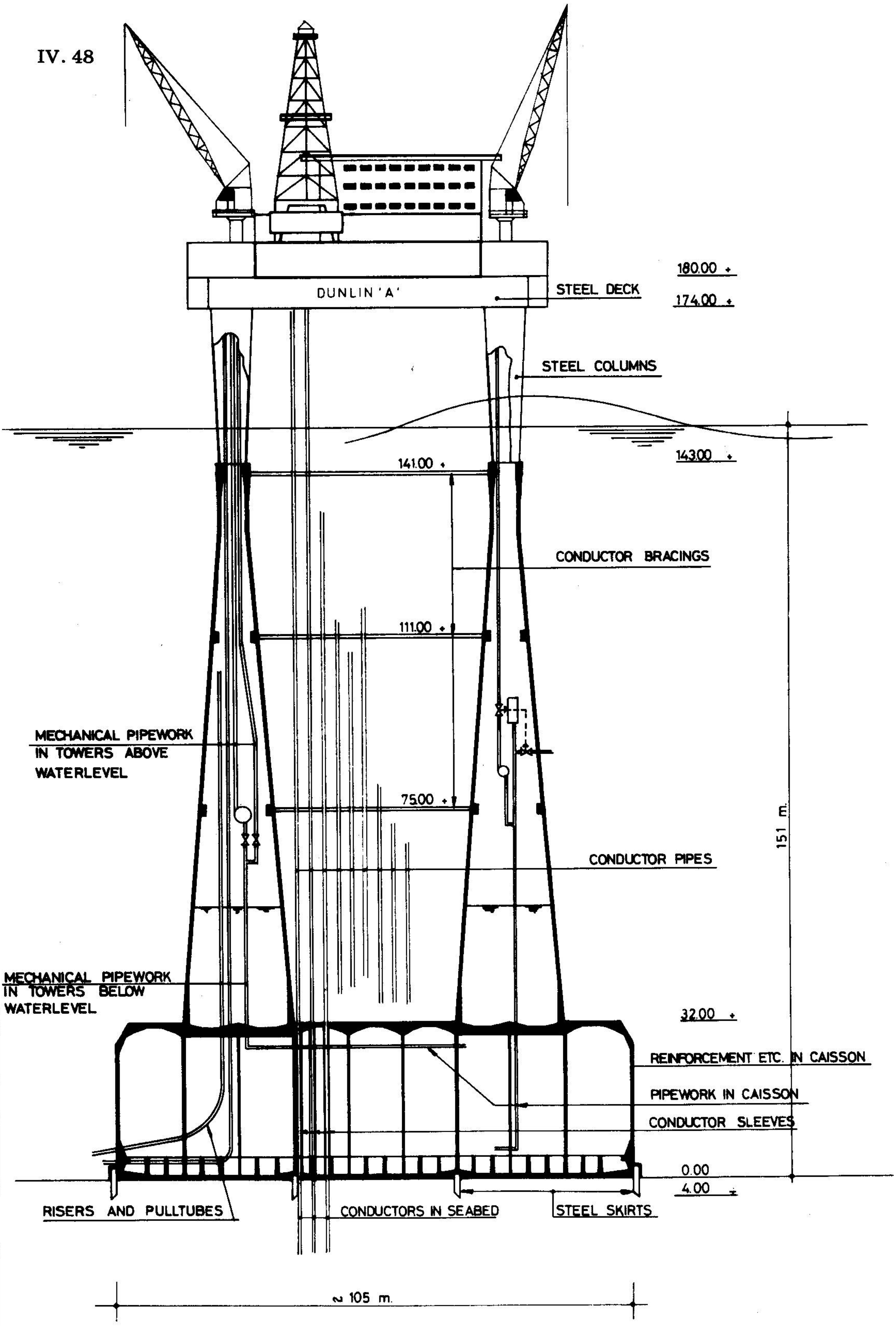
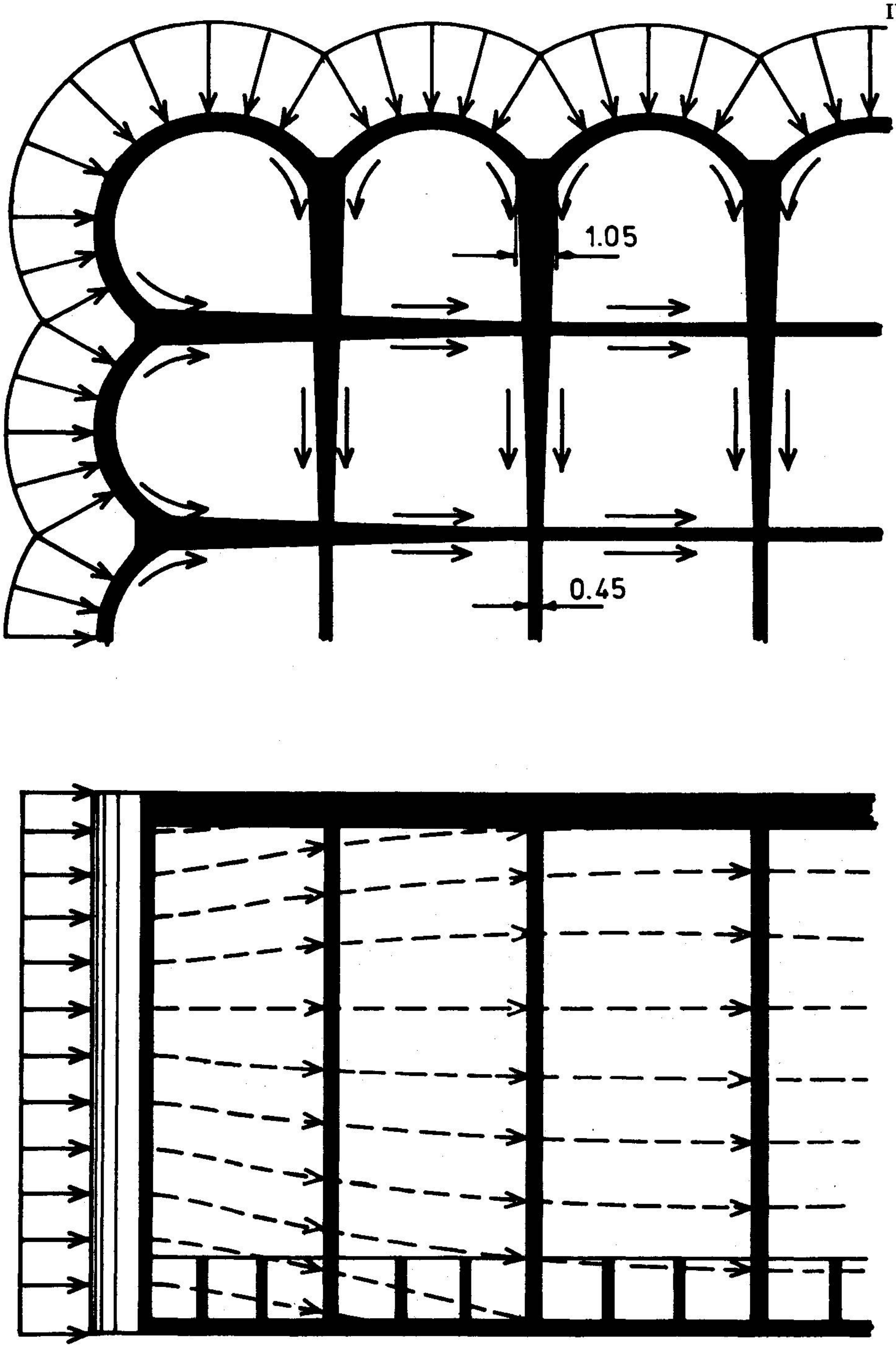


fig. 1

ANDOC



Distribution of outer arch loads over shearwalls, roof and bottom

Figure 2.

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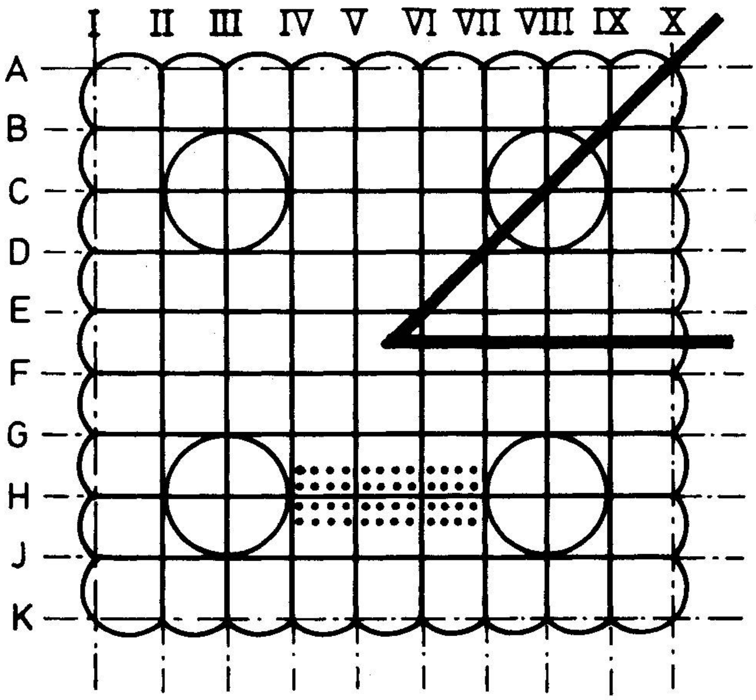
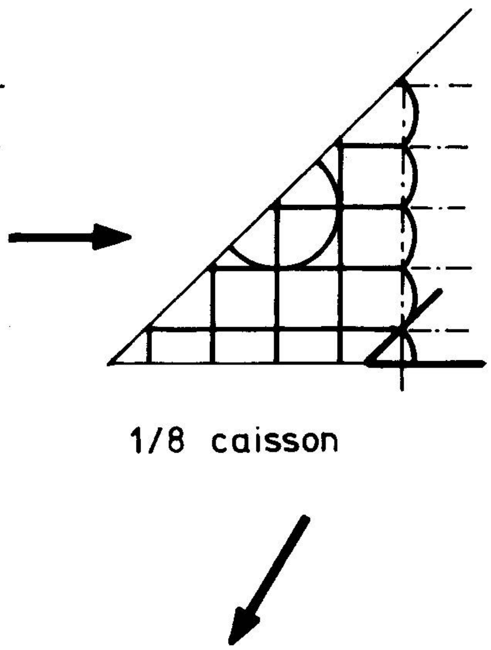
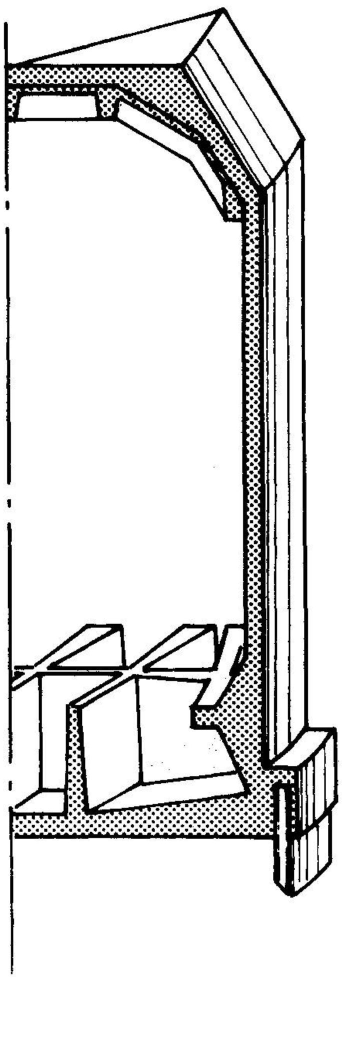
SUBDIVISION



entire caisson



1/8 caisson



half a cylindrical wall

Figure 3.

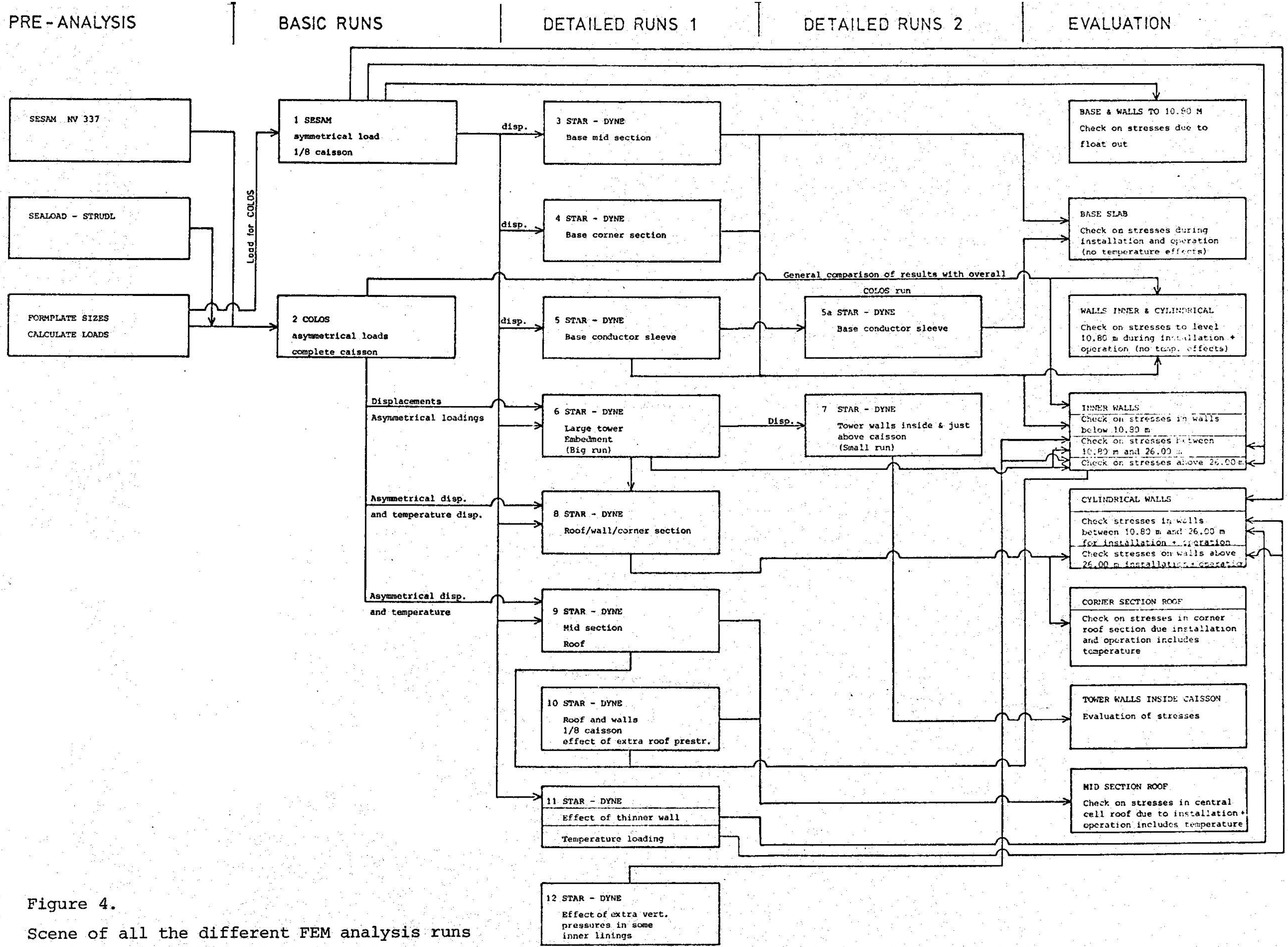


Figure 4.

Scene of all the different FEM analysis runs of the Dunlin A caisson.

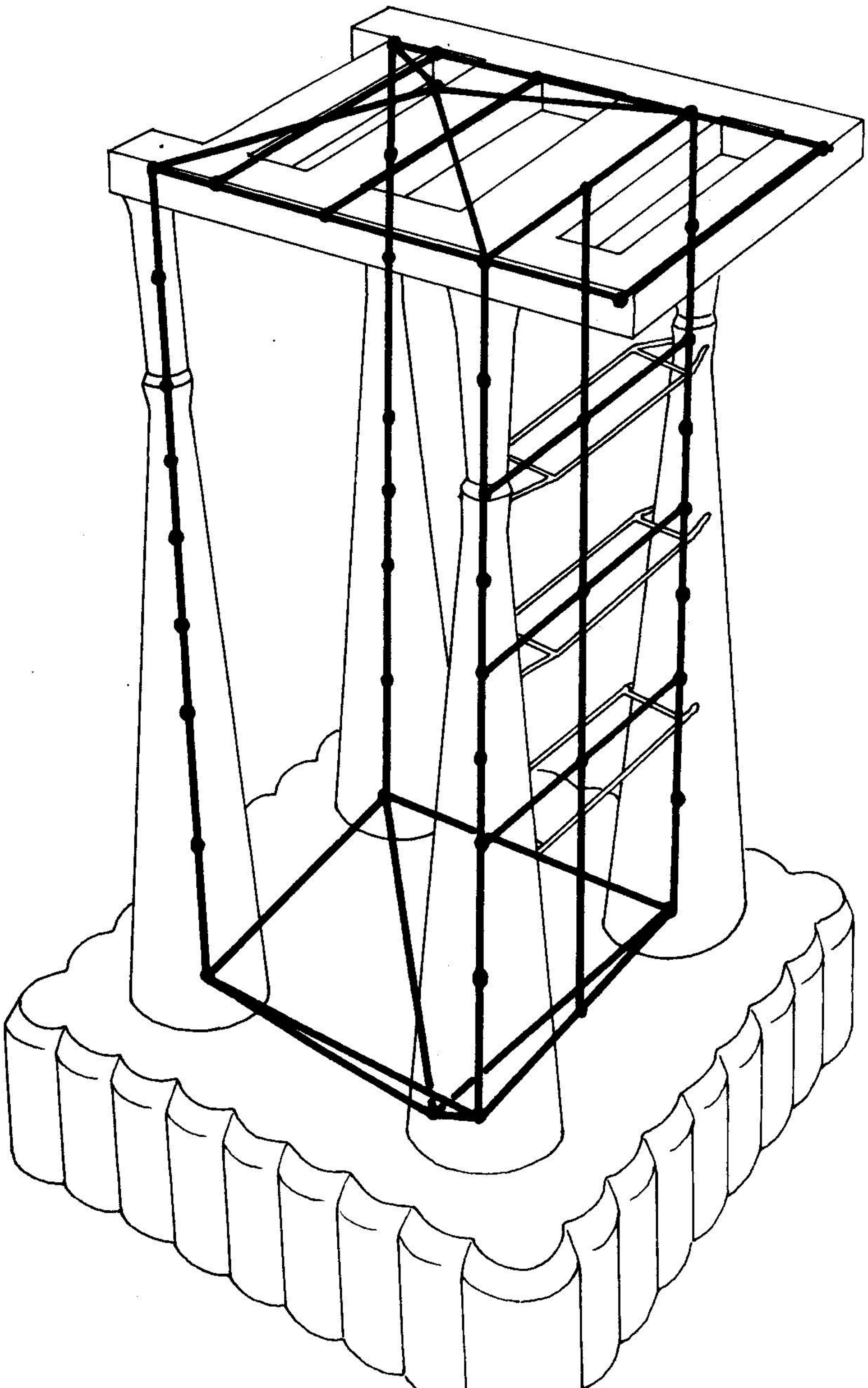


Figure 5. 3D Dynamic Model.