Concepts and Capabilities of

Computer Aided Deck Design & Optimization

McDermott Inc., Electronic Information Systems, New Orleans, La.

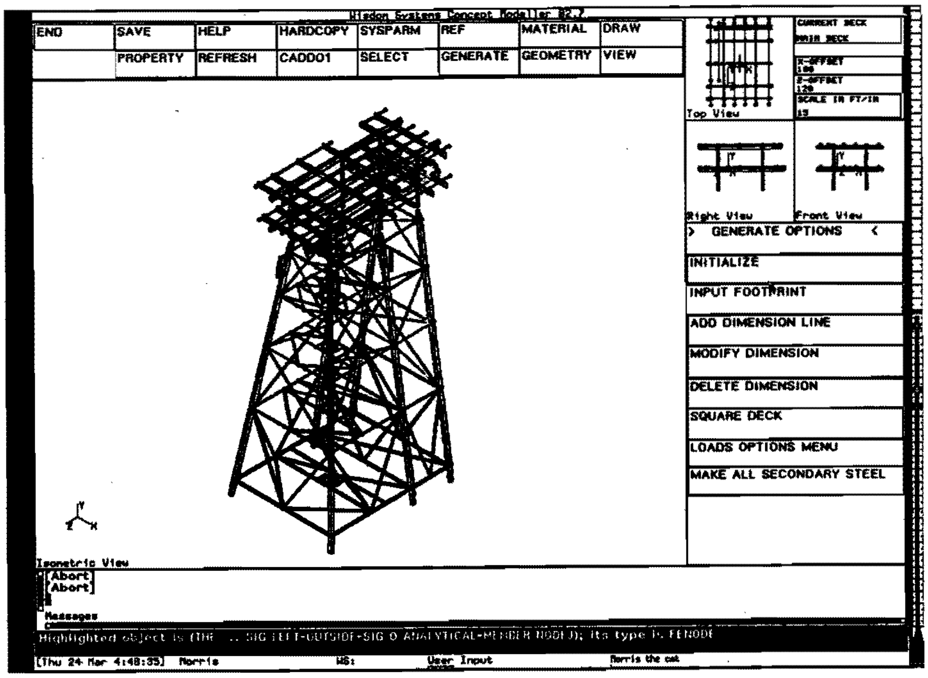

Figure 1 Trial Configuration for a 6-pile jacket & deck

Background

McDermott Marine Construction (MMC), designs, constructs and installs fixed offshore platforms. Oil companies use these platforms for drilling and producing oil and gas from hydrocarbon reservoirs found in water depths up to 1,350 feet.

Offshore technology is constantly improving and fixed platforms designed for 2,000'+ water depths are now being discussed. However, there are only a few "frontier structures", and the vast majority of the platforms are found in water depths less than 500 feet where field development risk and costs are more in line with the current price of oil and gas.

An offshore platform consists of two large prefabricated assemblies; a "jacket" and a "deck" (Figure 1). The jacket is fastened to the sea floor with piles, and supports the deck. The deck sits atop the jacket, above the water, and contains drilling and production equipment.

The jacket is a trapezoidal shaped frame-type structure built entirely of large steel tubulars. The jacket's "supporting columns" are called legs. Most shallow water jackets have either 4, 6 or 8 legs and each leg is typically 36" - 60" in diameter. Jackets are constructed on their side and then moved onto a barge for sea transportation to site.

Offshore, the jackets are taken off the barge, uprighted, and positioned on the sea floor. Piles are then inserted into the hollow legs and driven into the sub-sea soil to secure the platform against large storm waves. A typical 8-pile jacket in 250' water could weigh 2,000 tons and cost $55k to design and $2 million to fabricate.

The deck, which fits atop the jacket, is made up of supporting legs and two primary floor systems called the "main deck" and the "cellar deck". A typical 8-pile deck might have 25,000 s.f. of floor space and support 6,000 tons of drilling and production equipment. The structural part of this deck might weigh 500 tons and cost $45k to design and $1 million to fabricate.

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The fixed platform market is extremely competitive and contracts are often lost for less than 1% of the lowest bid. Although MMC enjoys 30% of the Gulf of Mexico market, the shallow water marketplace virtually has been taken over by small low-overhead companies. Contracts to design, fabricate, transport, and install shallow water platforms are often split between five or more companies. "Turn-key" design-fab projects, common in the past, are now rare. □

The Problem

Whereas MMC is a technological leader in the "frontier structure" marketplace, it desires to become more competitive in the traditional shallow water market, which has been taken over by smaller companies. This could be accomplished in part by improving the structural design schedule. If a platform could be designed in one month instead of the normal three months, "turn-key" design-fab projects might once again appear attractive. At the very least, Engineering profitability would improve, Engineering market share would increase, and cost cutting design-fab alternatives could even be proposed by the fabricators.

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MMC employs numerous mainframe structural design programs to design jackets. Although quite advanced, the existing systems are not capable of achieving the near-total design automation required for such dramatic schedule improvements. Moreover, platform deck designs still employ extensive use of time consuming hand calculations.

Total design automation would need to address both jackets and decks. Furthermore, drafting would also need to be automated since drafting, even with advanced CAD technology still constitutes up to 50% of the total design cost. Improvements would also be necessary in cost estimating, lofting, material take-off (MTO), purchasing, etc. if the construction disciplines are also to benefit. These improvements, if possible, would fall nothing short of a total revolution in current structural design technology. □

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The Solution

CADDO - The System

In May 1987, McDermott's Electronic Information Systems (EIS), New Orleans, started to automate the structural design of platform decks. Similarly, McDermott's Hudson Engineering Corp. (HEC), Houston, has concentrated primarily on jackets. Both projects promise to dramatically reduce the time required to design jackets and decks.

To automate deck designs, EIS New Orleans developed a Computer Aided Deck Design & Optimization (CADDO™) system which uses an object oriented programming shell called the *Concept Modeller*™ developed by McDermott's Wisdom Systems, Chagrin Falls, Ohio. The *Concept Modeller* acts as a sophisticated rule-based control system to generate model input and interpret output from external FORTRAN analysis and optimization programs. Interfaces were also written to tie into the existing mainframe systems and the *PDMS*™ drafting system, thus ensuring a "gateway" to larger systems like purchasing, cost estimating, drafting etc.

The CADDO system is made up of many programs. The *Concept Modeller* is the central control program and provides the user interface, model generator, and rules to communicate with the other programs. *INTRA*™ waveload is a program that generates loads on the structure caused by large storm waves. *Starstruc*™ is a finite element (FE) structural analysis program that computes member forces, selects an optimum member size, and performs an AISC/API code check. *GOS* is a girder design and optimization program that designs and optimizes AISC plate girders. □

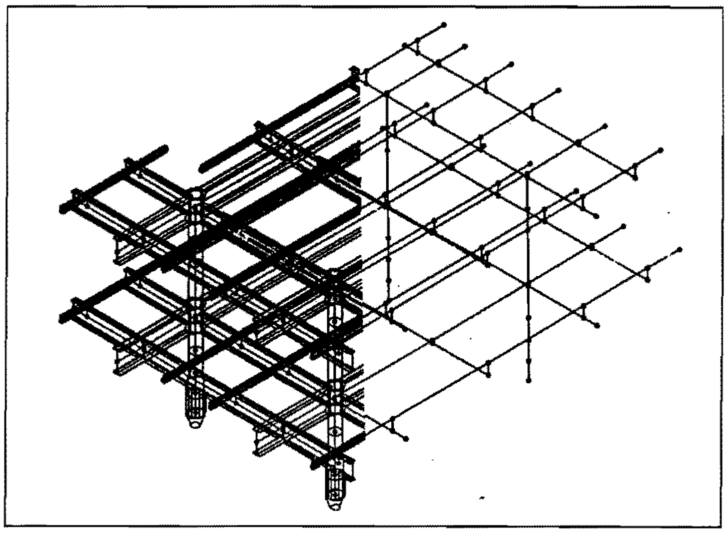

Figure 2 The Concept Modeller is used to create both the Physical and Analytical Models.

Features & Systems Used

The Concept Modeller

The *Concept Modeller* creates deck and jacket models based on rules governing the relationships between primitive three-dimensional objects, such as cylinders, plates, lines, points, cones, etc. These objects are described by names, dimensions or formulas, properties and orientation relative to other parts.

The Concept Modeller is the central control program

Parts are organized hierarchially into part/subpart "trees" which then show their logical relationship to other parts, key sub-assemblies, and the entire structure. As a result of this hierarchy, a small change in the depth of a plate girder would affect the plate girder's elastic properties, which would in turn affect the size of the deck legs, which would affect the... and so on. A change in any part of the structure may "ripple-through" and change a part on the opposite side of the structure - thus creating a "structural engineering spreadsheet" (so to speak).

The *Concept Modeller* system builds both a "physical" model and its "analytical" twin (Figure 2). The physical model can be visually displayed as it would actually appear; a beam looks like a beam. Similarly, its twin, the analytical model is created and can be viewed as it would "appear" to a finite element analysis program, complete with beam elements, nodes, etc. The *Concept Modeller* also computes member elastic properties and physical characteristics such as weight, surface area, and center of gravity. ☐

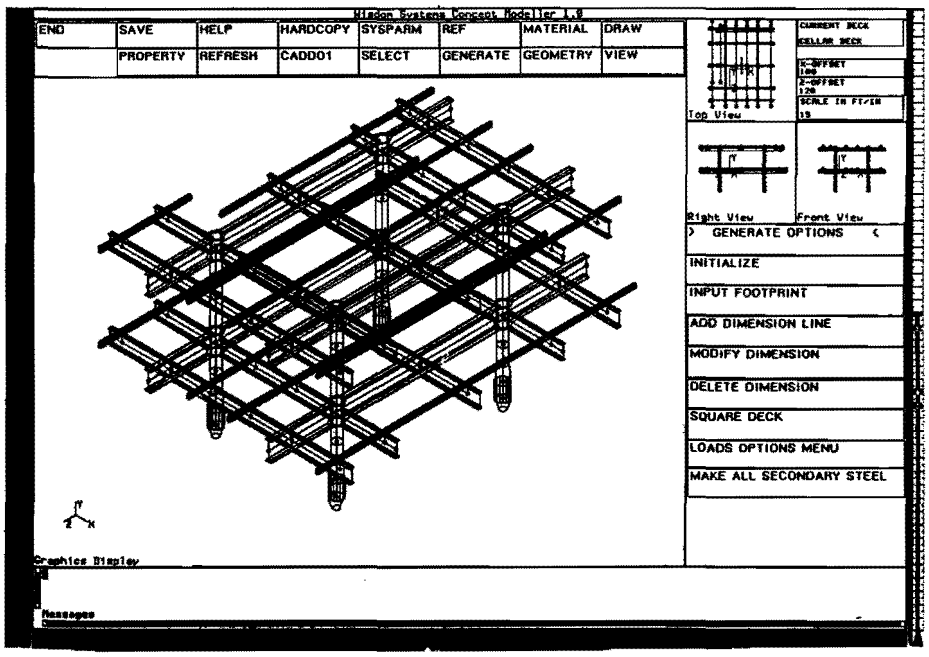

Figure 3 A typical 4-pile deck design generated by the Concept Modeller

The Deck

There are as many preferred deck designs as there are engineers. Some decks have trusses between the main and cellar deck, some have girders, and some have both. Decks can have floors made of steel plate, grating, and timber, and some decks do not have floors at all. Deck beams can be intercostal with girders or stacked atop girders. Many of these differences are required by the way a deck will be used. For example, decks that are used for jackup drilling, self-contained drilling, or production are designed differently.

CADDO will be able to handle different kinds of decks including traditional girder and truss designs. More importantly, it will be possible for the engineer to play "what if" games by comparing design alternatives. Cost and weight calculations will let the engineer find the most economical design, for example; plate vs. grating, truss vs. girder, etc. Also, a certain amount of detail steel is handled by the *Concept Modeller.* The system will design lifting padeyes, girder-leg connections, crane pedestals, stair landings, lateral bracing, conductor guide framing, etc.

Loads are "sketched-in"

As a starting point, a preliminary deck model is generated by the *Concept Modeller* based on user provided information (Figure 3). Basic questions such as number of legs, leg spacing, leg size, deck type, elevations, etc. are answered. The *Concept Modeller* then calls the various engineering analysis programs and receives back the correct structural sizes. This significantly simplifies the user interface to "unfriendly" engineering analysis programs.

Careful attention was also given to keep the CADDO system easy to use. "Pop-up" menus, mouse sensitive graphics, parametric dimensioning, windows, etc. were extensively used to minimize data entry. The engineer starts with a "graphpaper grid" and draws freehand a plan view of the deck using the mouse. When the sketch is complete, the user then edits the dimensions and the system re-draws the corrected view (Figure 4). Loads are "sketched-in" the same way (Figure 5). The system then computes the size and position of the supporting deck beams and the resulting floor system is then displayed (Figure 8). The engineer then moves, adds, or deletes beams as required for conductor guide framing, stair landings, etc. □

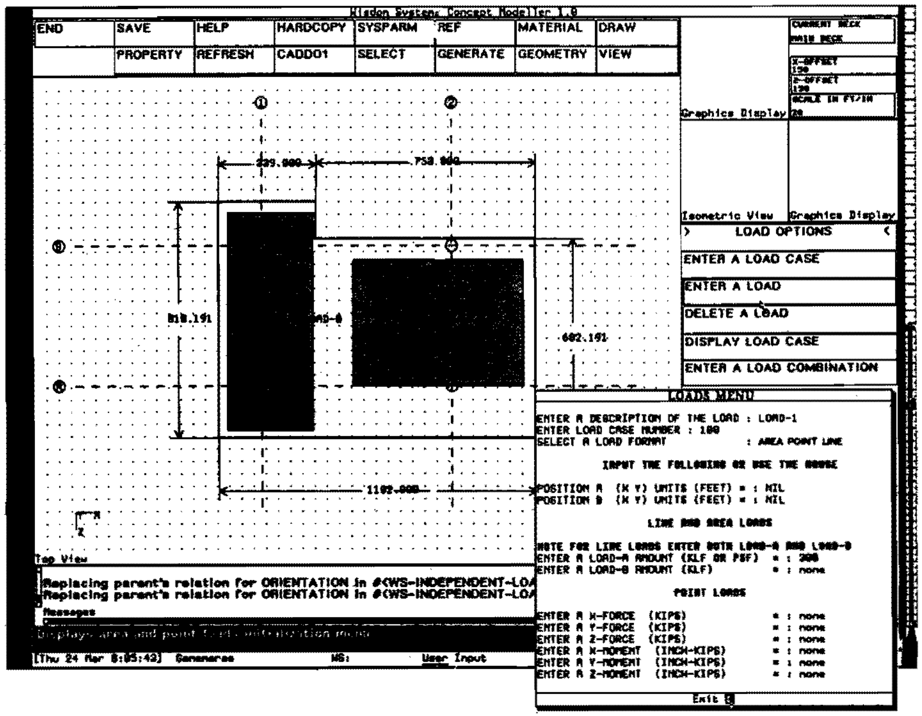

Figure 5 Live Loads are drawn on the deck

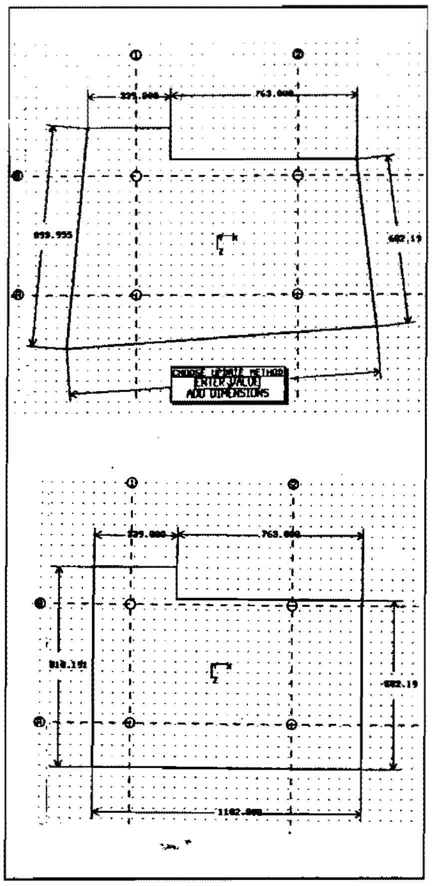

Figure 4 The deck is sketched-in using the mouse and then modified by changing parameter dimensions

The Jacket

Although the scope of the CADDO project did not include a jacket design, a jacket model is needed to simulate the structural stiffness and wave induced forces beneath the deck. A sophisticated jacket model is not required, but it is necessary to model some amount of detail like boat landings, conductors, pile inflection points, and the geometry of an existing jacket design.

The *Concept Modeller* was used to build rules and relationships for the physical and analytical jacket models. Careful attention was also given to making the system very easy to use. After completing a few mouse sensitive menu screens, the engineer uses the mouse to "pick and paste" desired truss patterns from a menu of graphic truss icons (Figure 6). Thus, a jacket can be modelled in a matter of minutes.

A significant amount of jacket information is automatically generated by the CADDO system. Member sizes, properties, and material are pre-selected based on D/t and KL/r principles and can be changed interactively. Waveload parameters are automatically set to account for anodes, marine growth, conductor groups, etc. The jacket can be either grouted or ungrouted. Member releases, effective member lengths and factors, jacket-pile connectivity, and other model geometry information is also generated.

The jacket model does not consider joint designs or segmented members since these are not required for the CADDO "dummy" jacket. Also, the CADDO jacket system is not fully automatic, as is the case with the McDermott's Hudson Engineering Corp. jacket design system (a separate development project which will automate shallow water jacket designs). CADDO is more interactive and requires the engineer to choose framing patterns, pile diameters, overall dimensions, etc. □

Finite Element Analysis

The goal of structural design is to achieve the most economical design that satisfies the engineering requirements. Ideally, the engineer would like to examine all the possibilities and find the optimum design that satisfies the physical and stress constraints, and at the same time, minimize construction costs.

Instead, the engineer must restrict his selection, based upon his experience, to a few possibilities because of schedule limitations. As a result, the engineer's design satisfies the stress constraints but it may not be the lowest possible weight.

In the past, the engineer started with the analysis of a trial configuration. He then evaluated the results, modified the model, and tried again. This might have been repeated several times until an acceptable design was achieved. Depending on the engineer's experience and the size of the model, this could take 4 - 5 days.

Structural Technology and Research Company, Bedford, Texas, working with McDermott, developed a sophisticated analysis program called *Starstruc* to automatically re-analyze a design while minimizing the weight by resizing members based on computed AISC/API allowable stresses. Furthermore, the analysis process is restricted by known physical constraints like maximum and minimum values for member depth, width, and thickness. It is also possible to group, link or fix member sizes so that, for example, all of the deck legs end up with the same diameter and all of the deck girders are of the same depth.

The *Concept Modeller* controls the *Starstruc* program and predetermines which members will be linked together by a common dimension, which materials will be used, which load cases are to be combined, and what is the first trial configuration. The design results are then returned to the *Concept Modeller* and the model is updated. □

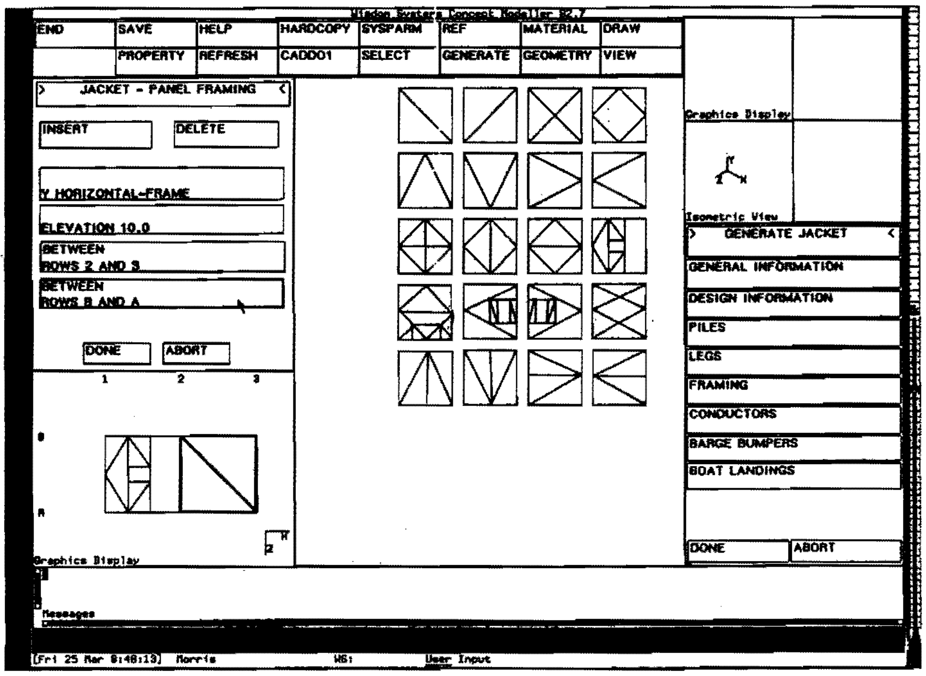

Figure 6 The Engineer uses the mouse to pick and paste desired truss patterns from a menu of graphic truss icons

Plate Girder Design

Plate girder decks have taken on new importance to McDermott's fabrication division since its recent purchase of an automated girder fabrication facility. This facility will cut the cost to fabricate girders in half. If girder decks were more common, McDermott fabricators would be more competitive.

Plate girders are currently designed by hand and there are no known computer programs available to design AISC plate girders. Therefore, it was necessary to develop a girder design program completely from scratch. A contract was signed with an outside consultant with previous experience writing a program to design AASHTO bridge girders.

AISC plate girder designs for decks are extremely complicated. A design must consider 6 degrees of freedom and any number or type of loads from any direction. The allowable stress calculations are complex, highly nonlinear and discontinuous. Also, girder calculations must consider hybrid designs, stiffened vs. unstiffened, bearing stiffeners, up to 50 load cases, and cost optimality.

Perhaps the largest problem was deciding on whether the girder should be designed for minimum weight or minimum cost. If a girder is designed for minimum weight, it might have costly web and flange splices every 5 feet and numerous transverse stiffeners. Therefore, it was decided to write the program to design girders for minimum cost. Detailed labor cost tables were then written based on months of field time and motion studies. The program uses these cost tables to determine whether or not it is economical to splice the web or flange in order to save material.

... Plate girders are currently designed by hand ...

The *Concept Modeller* provides dimensional constraints to the girder program and the previously executed finite element analysis program provides member end forces. The optimized girder design results are then returned to the *Concept Modeller* to be interpreted. □

Automated Drafting

A typical 8-pile deck might have 30 structural drawings at an average labor cost of $500 per drawing. Approximately half of these drawings can be produced automatically based on information generated by the *Concept Modeller*. This will lower the project's total structural drafting cost by approximately 20% - 30%.

The *Concept Modeller* is used to format three-dimensional data to a DESCON file that can be read by *PDMS*. Plan and elevation main steel drawings will be passed complete with information for the proper scale, title block, drawing annotation, dimension lines, etc.

Once the three-dimensional geometry is passed to *PDMS*, a set of macros is used. These macros permit access to *PADDLE*, a sub-system of *PDMS*, and enable fully annotated scale drawings to be produced. □

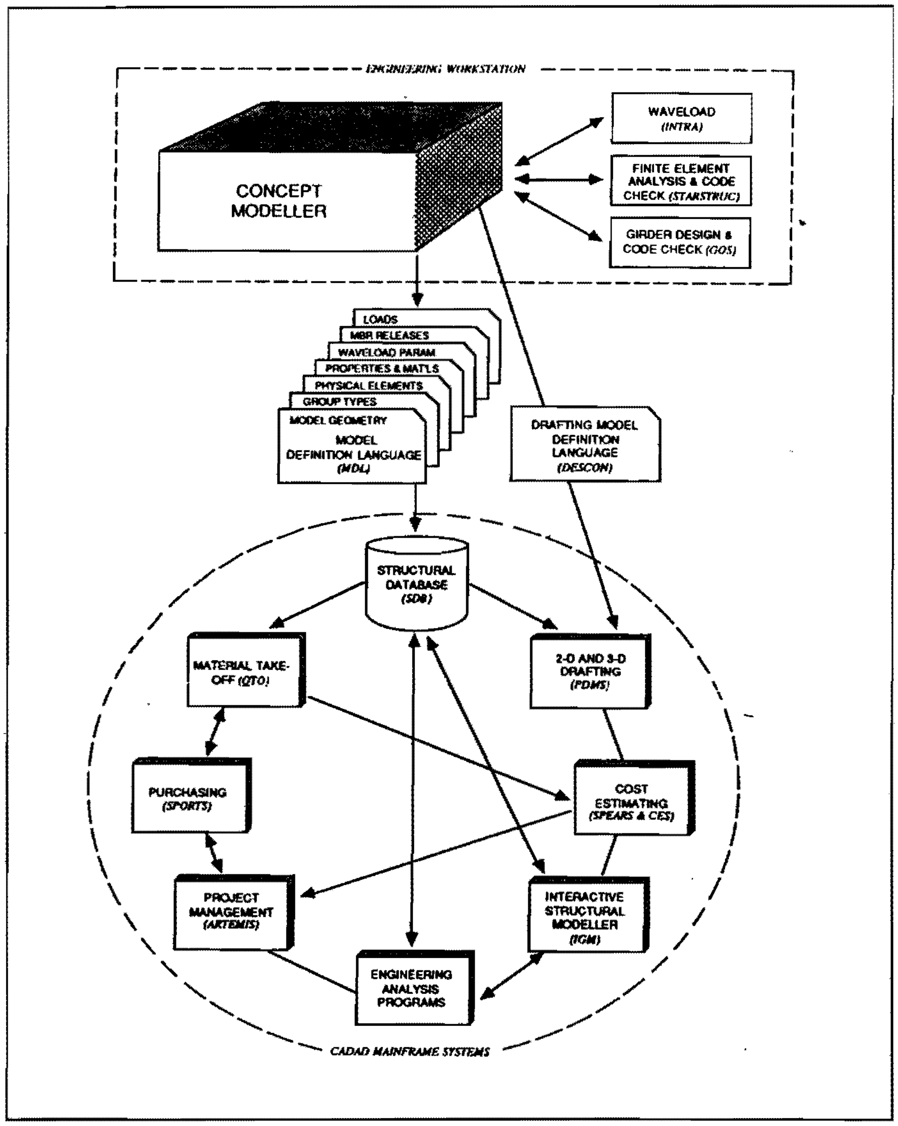

Figure 7 CADDO information can be provided to the IBM Mainframe

The Mainframe Interface

There are many engineering and project management systems already in place on the McDermott IBM 3084 mainframe. A *Concept Modeller* "gateway" to these systems is advantageous for a multitude of reasons. Of immediate interest, the mainframe engineering analysis programs provide a means of quality assurance (QA). After a final CADDO deck design has been completed on an engineering workstation, the model can be passed to the mainframe where it can be re-analyzed and verified.

CADDO information will be provided to the mainframe purchasing, material take-off (MTO), and cost estimating systems for project management purposes. Many of the systems already interface with one another and a link into this existing network is essential.

Information is passed from CADDO in the form of flat files via an SNA link to the Structural Data Base (SDB)(Figure 7). The data is pre-formatted by the *Concept Modeller* in accordance with McDermott's Model Definition Language-Communication (MDL-C) file specification, universally used by other McDermott programs. The complete model is passed, including loads, group types, member releases, etc. This information is then available to all of the systems that access SDB. □

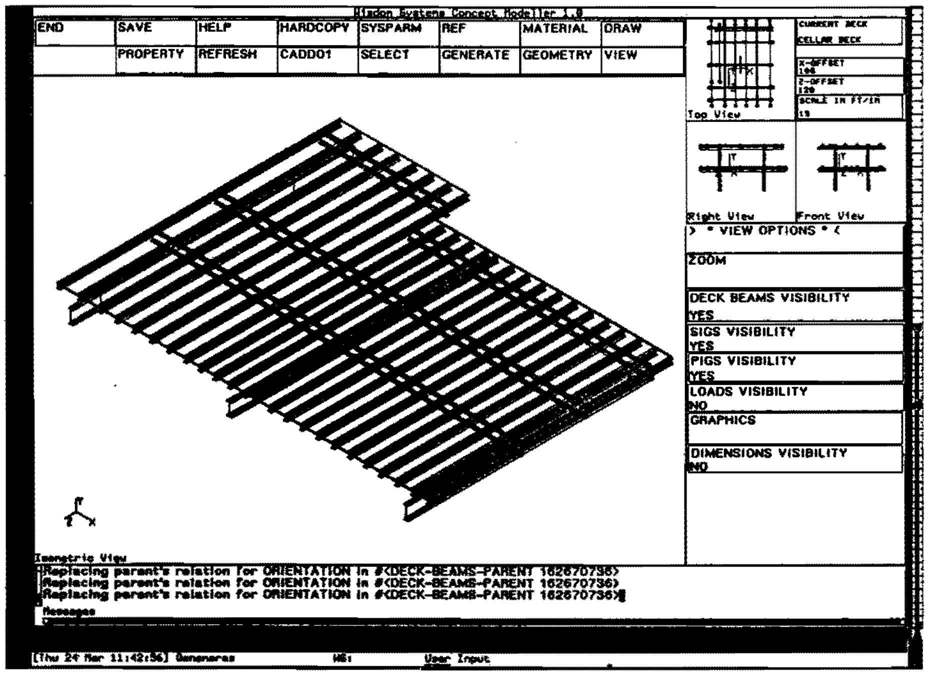

Figure 8 Deck beam positions and sizes are automatically generated

Workstation Hardware

The speed and performance of Engineering Workstations is doubling each year and in an extremely competitive hardware market, it is not clear which vendor will survive the next 5 years. For this reason, careful attention was given to using standard computer languages like Common LISP and FORTRAN-77, which are portable between different workstation vendors. For example, the CADDO project purposefully avoided using *Symbolics*™ LISP at the expense of improved performance because *Symbolics* LISP is not portable. Current plans are to deliver CADDO on a *Sun*™ 4/260 workstation. □

Benefits

The CADDO project provides benefits to both the engineering and the construction disciplines. The obvious gains in engineering will be in fewer manhours and a shorter design schedule. It is expected that deck designs will cost half as much and take half as long. But gains will also be made in the final product.

The engineer will be able to spend more time evaluating different design alternatives. Moreover, the design quality will improve because CADDO will replace hand calculations which are more prone to human error. The use of design optimization techniques will also lower the final cost to the customer because construction labor and materials will be saved.

Based on previous engineering studies, it has been shown that a 10% - 15% cost savings could be realized if certain decks could be redesigned. Most customers are unable to justify the additional engineering expense required to evaluate the cost differences between competing design alternatives. Also one deck design may be re-used on 10 different platforms, with each deck weighing a little more than its predecessor because of add-ons.

One solution might be to offer customers a more economical deck design alternative, together with the base bid, when the fabricators are asked to bid on construction. Admittedly, there will be some resistence to this idea and many oil companies would reject this concept outright. However, this may not be true with the smaller oil companies that are interested in the lowest possible cost.

With the prospect of creating main steel designs in a matter of days instead of weeks, oil companies may choose to rethink the idea of "turn-key" design-fab contracts. A day late installing an offshore platform is one day of lost oil production. At today's prices, that might be around $50k/day. Therefore, if McDermott could shorten the design-fab schedule by one month in a "turn-key" project, the early production revenue would equal almost 30% of the cost to design and build the whole platform. □

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