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Proceedings of the REAPS Technical Symposium

Paper No. 24:
The Application of a CNC Frame Bender within an Automated Shipyard

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

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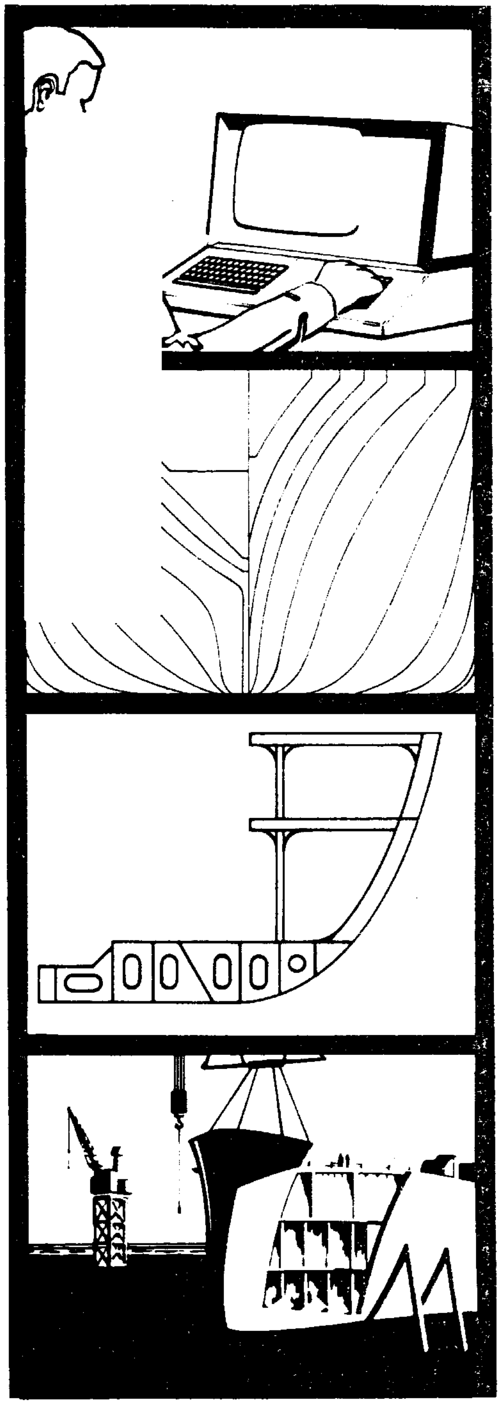

R ESEARCH AND **E** NGINEERING FOR **A** UTOMATION AND **P** RODUCTIVITY IN **S** HIPBUILDING

Proceedings of the REAPS Technical Symposium

June 21-22, 1977

New Orleans, Louisiana

THE APPLICATION OF A CNC FRAME BENDER IN AN AUTOMATED SHIPYARD

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Mr. Mackey is President and General Manager of Hyde Products, Inc. A naval architect and marine engineer, he has been in the shipbuilding and equipment business for 20 years. His M.S.E. and B.S.E degrees tire from the University of Michigan.

INTRODUCTION AND SUMMARY

The CNC frame bender is a machine being developed to utilize a computer controlled method for the cold forming of ship frames, especially large steel beams. The technology being incorporated will: (1) shape ship frames by applying mostly pure bending moment to the members - a four point bending action instead of the conventional three point bending; (2) use computer control with feedback to carry out the bending, including corrections for springback; (3) eliminate out-of-plane deformation by built-in computer routines that correct incipient errors detected during the bending; and (4) straighten beams in both horizontal and vertical planes. The frame bender will handle beams with either symmetrical or asymmetrical cross sections.

Research on the development was commenced by Dr. H.W. Mergler (School of Engineering, Case Western Reserve University, Cleveland, Ohio) and associates D.K. Wright, T. Kitcher and M. Savage, along with various graduate assistants, in August 1972, with an 18-month grant from the National Science Foundation Research Applied to National Needs program (NSF/RANN). Following subsequent grants, including one jointly funded with the Maritime Administration, the project was completed in July, 1976. A bench. scale model of the beam bending aparatus (See Figure 1) has been constructed and successfully demonstrated by Dr. Mergler and associates; development and utilization of a full size machine by a shipyard is the next step.

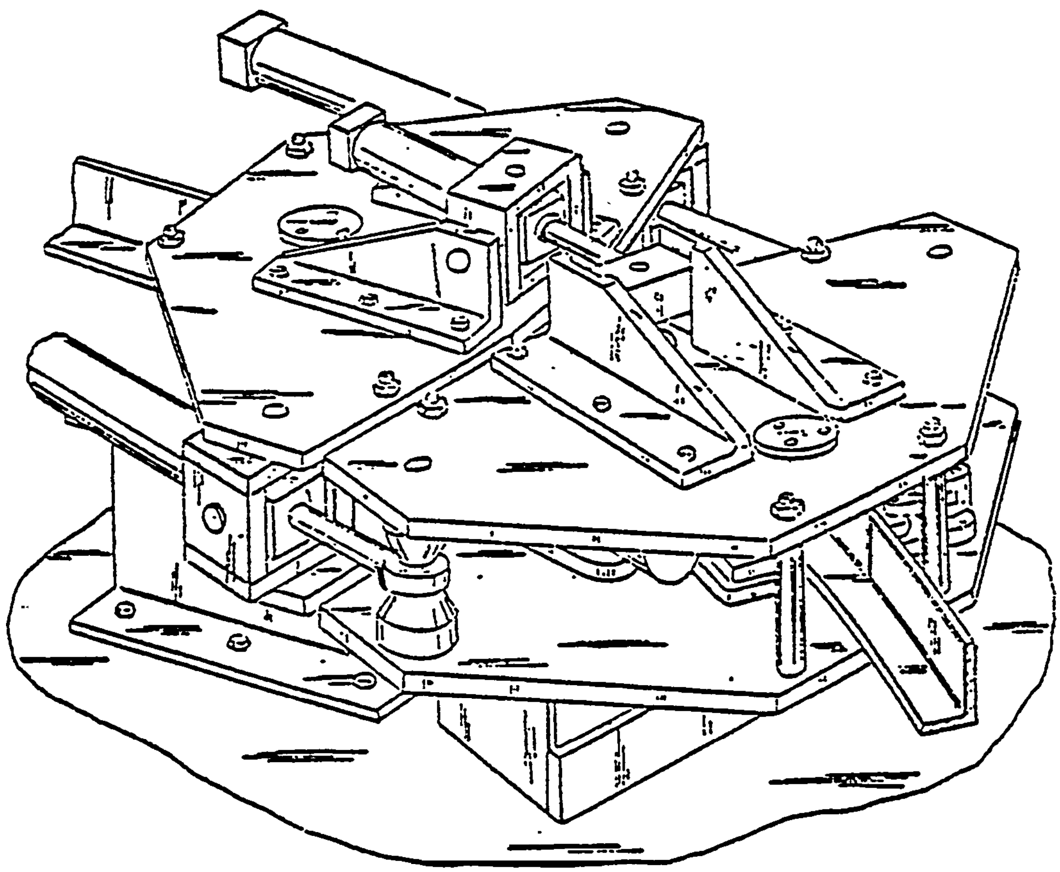


Figure 1(a)--Perspective View of the Model Through Feed Bender

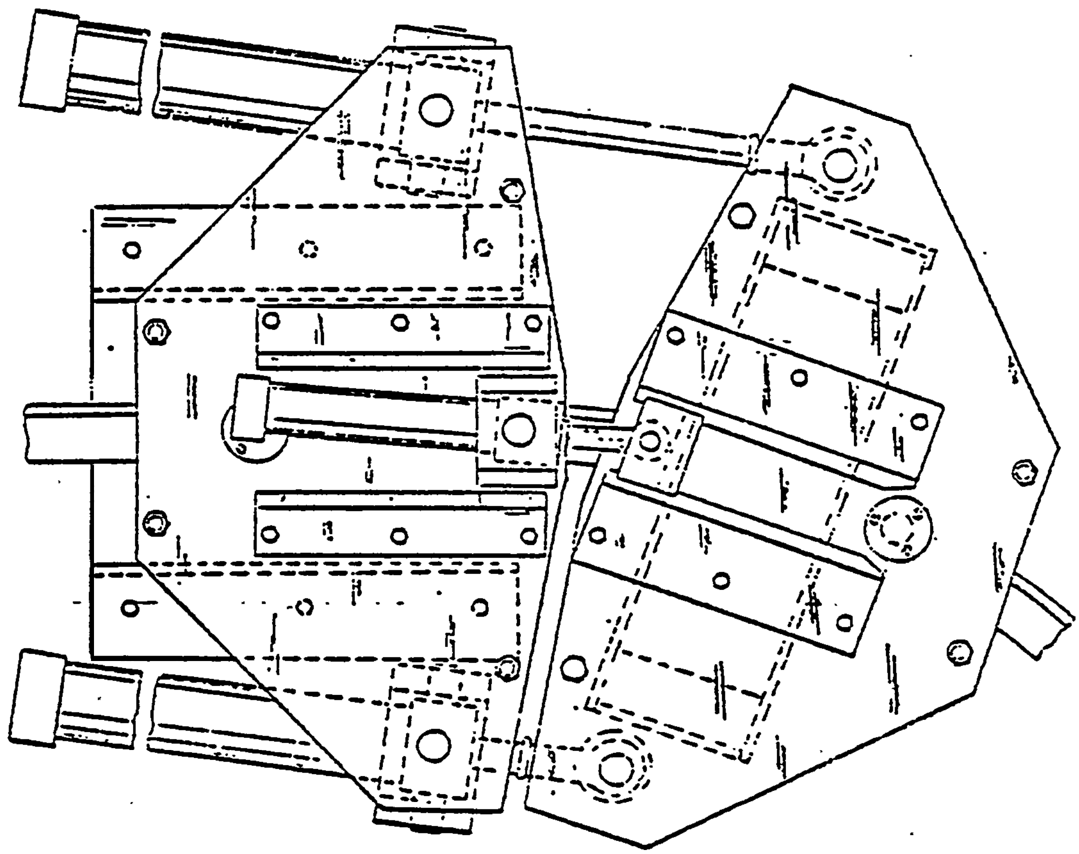


Figure 1 (b)--Top View of the Model Bender

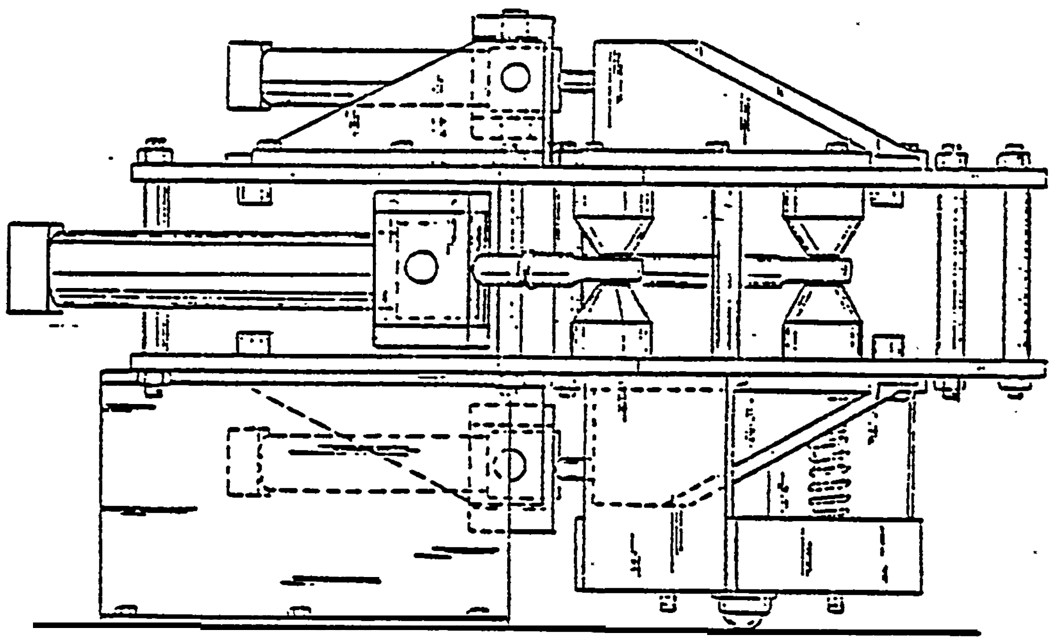


Figure 1 (c)--Side View of the Model Bender

Over the past year, National Steel and Shipbuilding Company has completed an internal analysis of the cost effectiveness of an automated beam bender for their operations, and are convinced that the Case Western bender is the best technology available. Concurrently, the Naval Sea Systems Command, under" the Defense Department's Manufacturing Technology Program, has evaluated the Case Western beam bender as a candiate for their . support; their plan is to fund the building of a full scale model which NASSCO will use as government furnished equipment. Contract negotiations are currently in process with a goal of an operational machine by mid-1$179. Hyde Products Inc., a subsidiary of Zimmite Corporation specializing in custom machine design and construction, has been granted an exclusive license to market the Case Western beam bender and will be the manufacturer of the machine.

NASSCO FRAME BENDING REQUIREMENTS

NASSCO has developed a method of shipbuilding utilizing fabricated angles and tees (frames) which permits the use of different thicknesses of metal for web and flange and which results in greater strength with lighter weight at less cost (see Figure 2). These frames are cut from flat plate on the flame planner and transported by conveyor to the automatic "tee-welder" where they are welded. Maximum size is 40' in length with a 25" wide x 1/2" thick web and 8" wide x 1" thick flange. The welding process results in deformation of the frame and although annealing torches are applied to the edges of web and flange to minimize this effort, about 95% of these frames require straightening before use

FRAMES FOR WELDED SHIP CONSTRUCTION

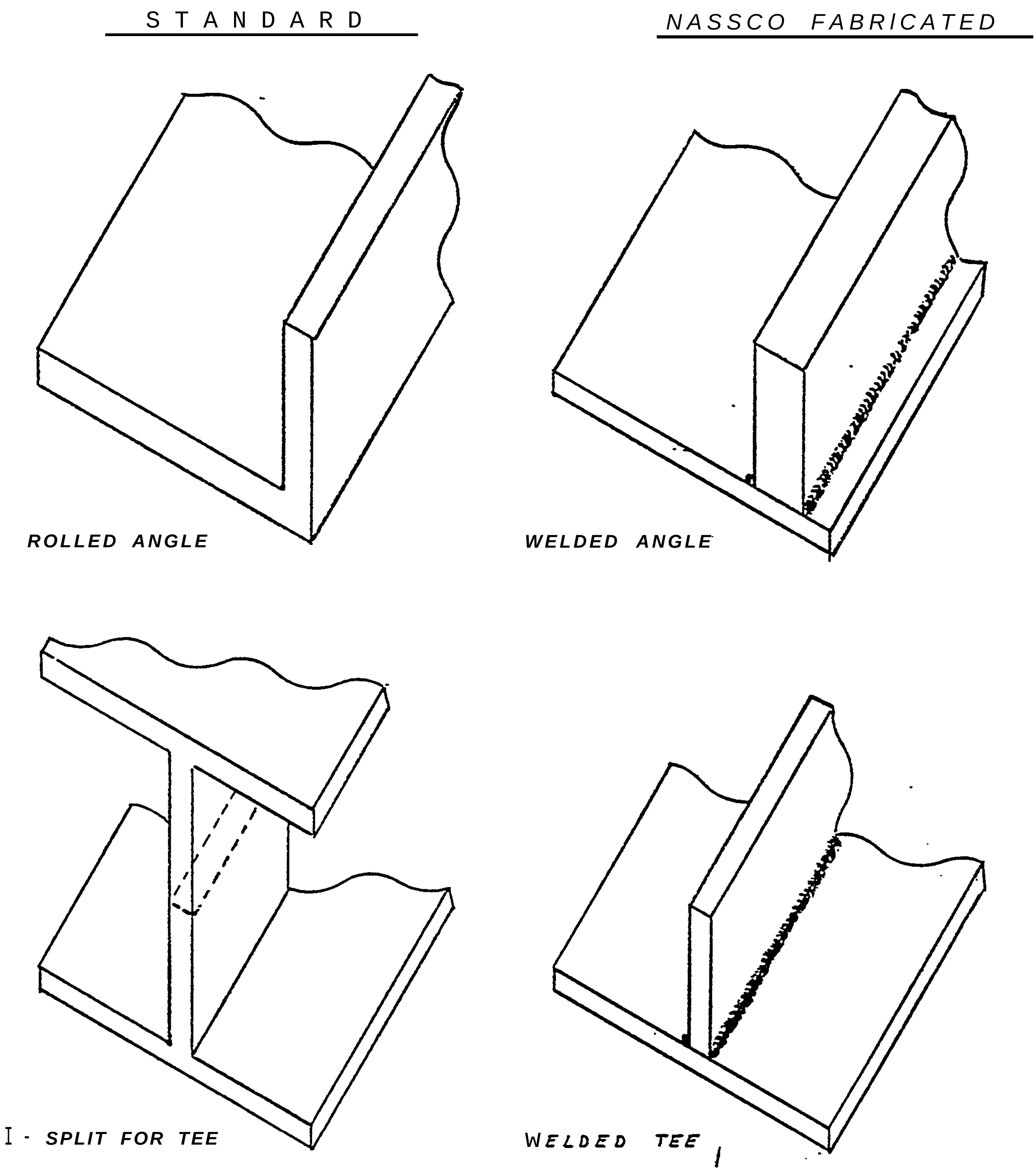


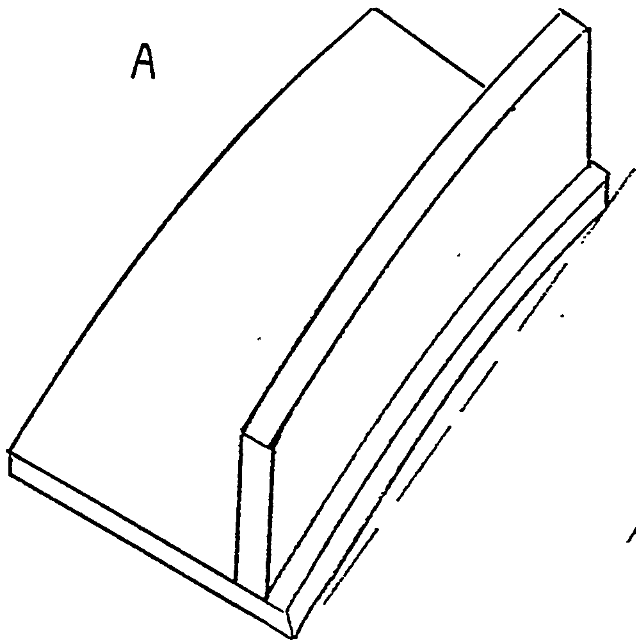
FIGURE 2

(see Figure 3).

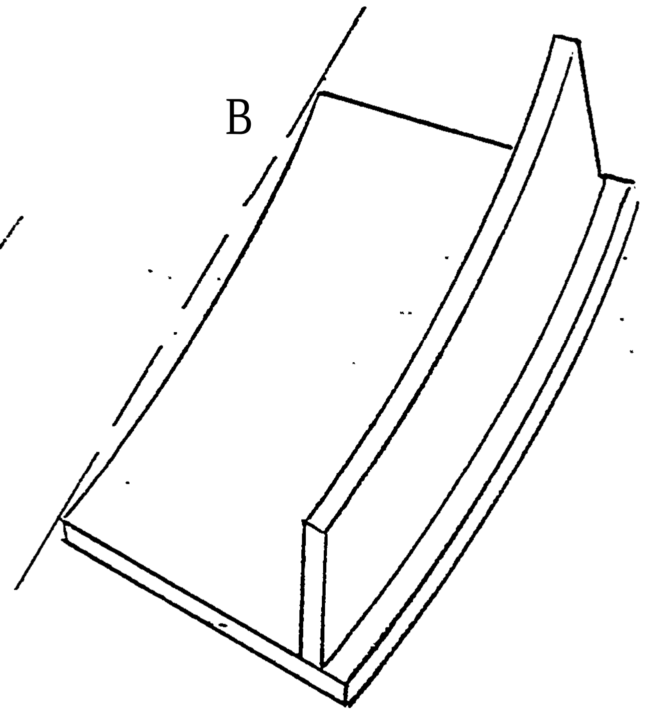
Most of the shaped frames are bent around the web, which cannot have any wrinkles (see Figure 4). Current facilities are confined to hot forming, using a natural gas-fired furnace. With average labor cost of $152.00 plus fuel cost of $66.00 each, the projected increase in gas rates (see Figure 5), and the potential shortage of natural gas, this method of forming will be increasingly prohibitive. In addition, such heavy use of the furnace results in more rapid deterioration and a higher rate of repairs; in 1975, repair costs amounted to over *$28,000.00.* Another detrimental aspect of hot formed frames is that they change shape slightly during cooling resulting in additional costs during assembly (see Figure 6).

Frames that are installed as straight sections must be free of deformation. In most cases, the deformation is removed on a Cleveland #2, 200-ton capacity straightening and bending machine ("bulldozer") capable of a maximum beam size of 24", horizontal or vertical. Operating at 28 straight- per minute, the frame is beaten until it appears straight to the naked eye. When deformation is in 2 planes, the frame is first straightened in one plane, removed from the machine, the holding fixture changed and the frame straightened in the second plane. One frame costs $11.50 (labor) to straighten. If deformation is around the flange (Figure 3A) and is not too severe, straightening can be accomplished by heating portions of the web with a portable torch. Severe deformation must be straightened using the gas furnace. If the deformation is in the form of a twist (Figure 3D), the straightening operation must be done in the gas

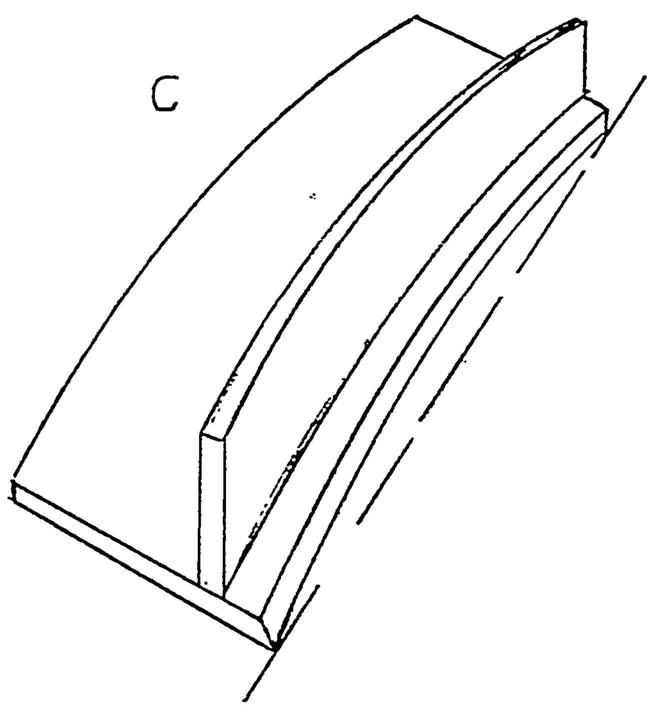
DEFORMATION OF WELDED FRAMES



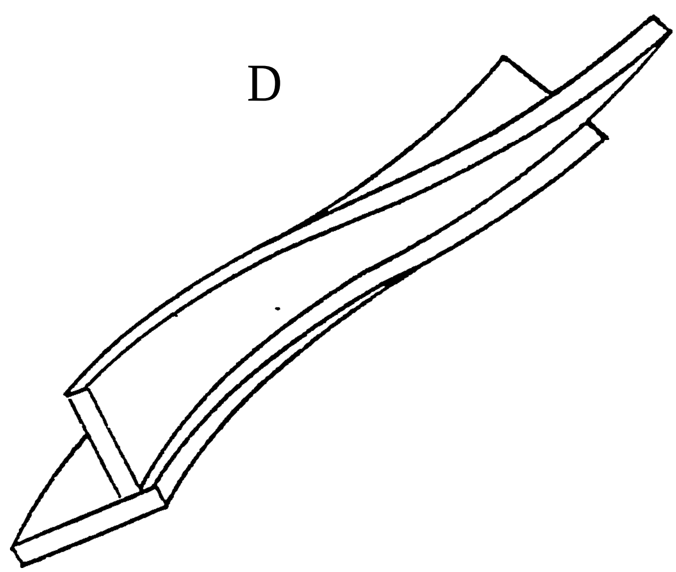
WARP AROUND FLANGE



WARP AROUND WEB



WARP IN VERTICAL PLANE



TWISTED

FIGURE 3

WRINKLED WEB

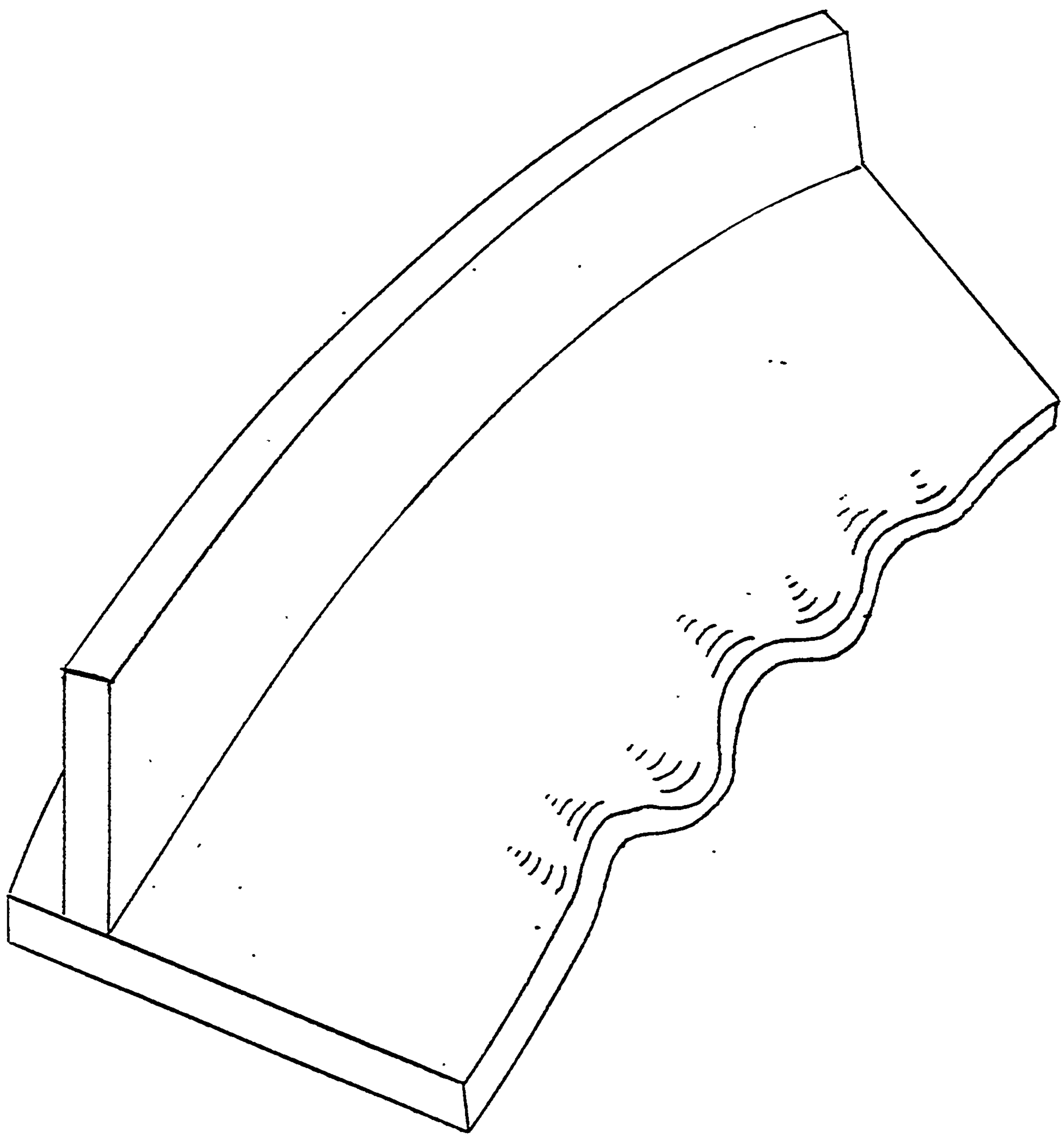
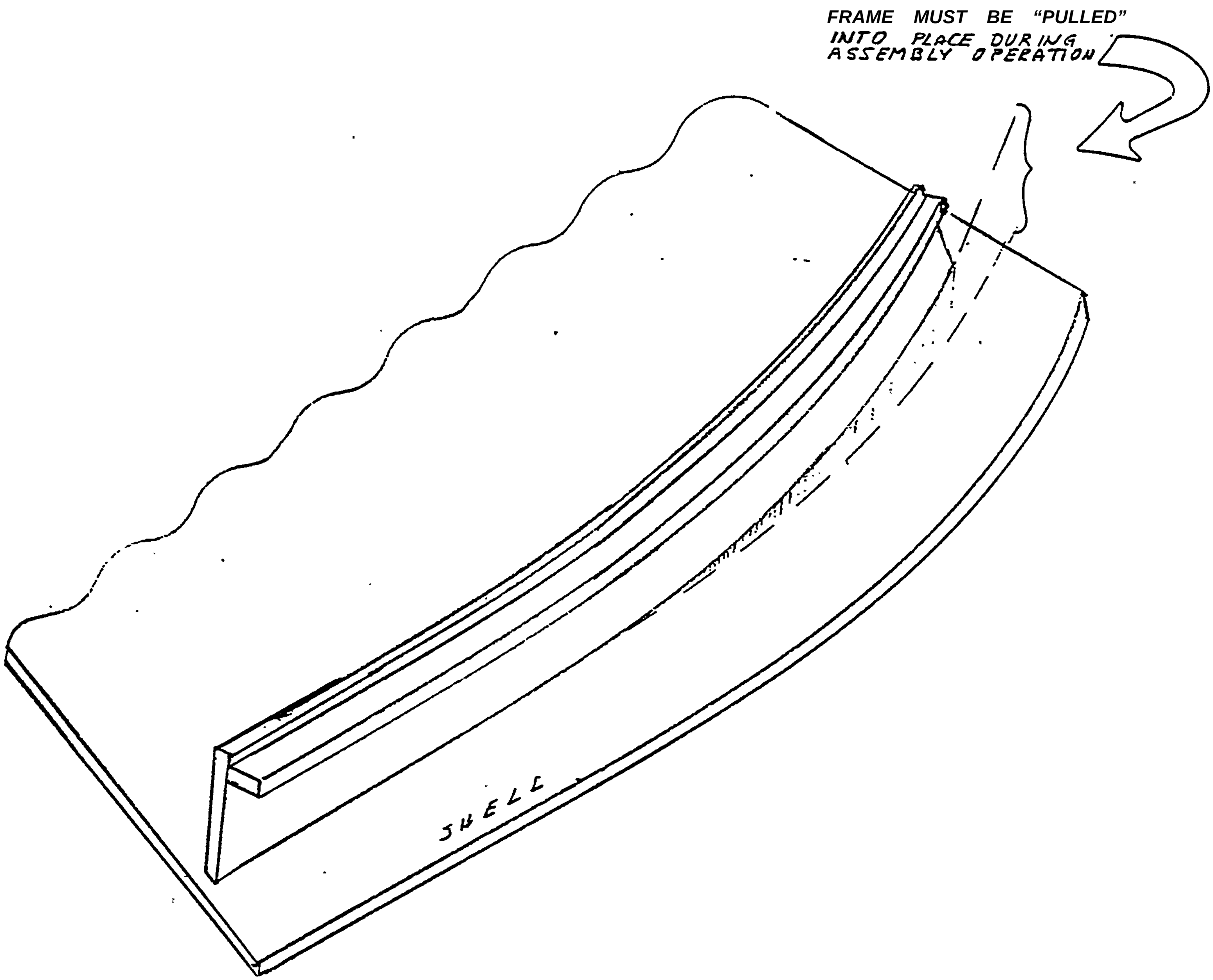


FIGURE 4

COST PER MILLION BTU

	1974	1975	1976	1977	1978
ELECTRICITY /KWH	$6.15 / .021	$7.91 / .027	$12.31 / .042	$16.99 / .058	$18.75 / .064
NATURAL GAS /THERM	$ .61 / .061	$1.10 / .110	$2.50 / .250	$3.40 / .340	$5.10 / .510
PROPANE /GALLON	$3.59 / .33	$4.13 / .38	$5.00, / .46	$5.65 / .52	$ 7.07 / .65
DIESEL /GALLON	$1.85 / .26	$2.77 / .39	$ 2.99 / .42	$ 3.56 / .50	$3.92 / .55

INCORRECT FRAME CONTOUR



furnace. It should be noted that the smaller, lighter-weight tees used on Navy ships distort in more planes and are more difficult to straighten (in the bulldozer) than the heavier angles used on commercial tankers.

FRAME BENDING ANALYSIS

Obviously, any frame bender would improve the situation; however, NASSCO has elected to proceed with the CNC approach and, since commercial beam benders are available, the application of the CNC famebender should be evaluated in relation to the differences between it and those rather than with hot slabbing. Therefore. a brief review of those differences is in order.

The method used by NASSCO to form bent members for ship frames has been to fit each newly bent member to a precut wood template; a number of beam benders use the method of straightening out the inverse of the desired bend, which has been chalked from a template onto the member to be bent. Both methods are trial-and-error and require skillful operators to produce accurate results within a reasonable time. A second, more critical disadvantage of both present systems is the use of a three-point bending method. Such a bend causes large shear stresses and consequently, undesirable twisting and out-of-plane bending; the latter is especially acute in bending beams with asymmetrical cross sections.

The technique developed by Dr. Mergler and his associates at Case Western Reserve University avoids both problems. Their technique depends upon what is essentially a four-point bending action to achieve zero shear force bending over the bulk of the bend. It relies upon independent control of the plane-of-moment application and feedback corrections in order to avoid out-of-plane deformation.

The forces and moments associated with the two basic bending method are sketched in Figures 7 and 8. The conventional three-point bending produces shear forces throughtout the bent member; the four-point loading achieves zero shear forces (i.e., constant bending moment) along most of the bend, a highly desirable feature in bending.

In pure bending, the beam is gripped at two points and bent exerting pure moment forces on the beam (see Figure 9). In the ideal case, there is zero shear force over the entire length of the beam. Since in the realistic case a finite gripping area is needed, shear forces do exist in this region and the bending is equivalent to four-point bending rather than to idealized pure bending (see Figure 9A).

To minimize the unavoidable out-of-plane deformation experienced in bending beams of asymmetrical cross section when using conventional equipment, the Case Western bender separates the plane-of-moment application from the desired plane of deformation (see Figure 10). In order to avoid out-of-plane deformation, the plane in which the moment must be applied does not coincide with the principal axis of the beam. Thus, to bend the angle beam in the plane of the major web, the moment must be applied in a non-obvious plane (Figure 10). Before bending this beam with the Case Western machine, a calculation of the separation angle between the two planes is made and once the bending is underway , corrections in the separation angle are made as needed to eliminate out-of-plane deformation. Since conventional beam

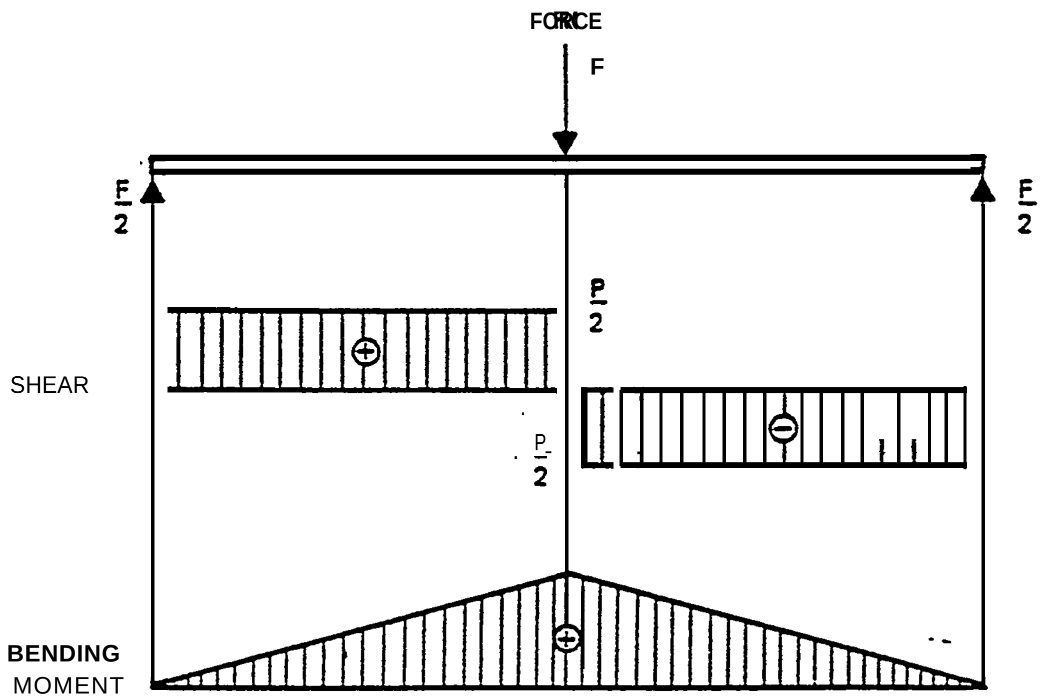


Figure 7 . Traditional Three-Point Bending.

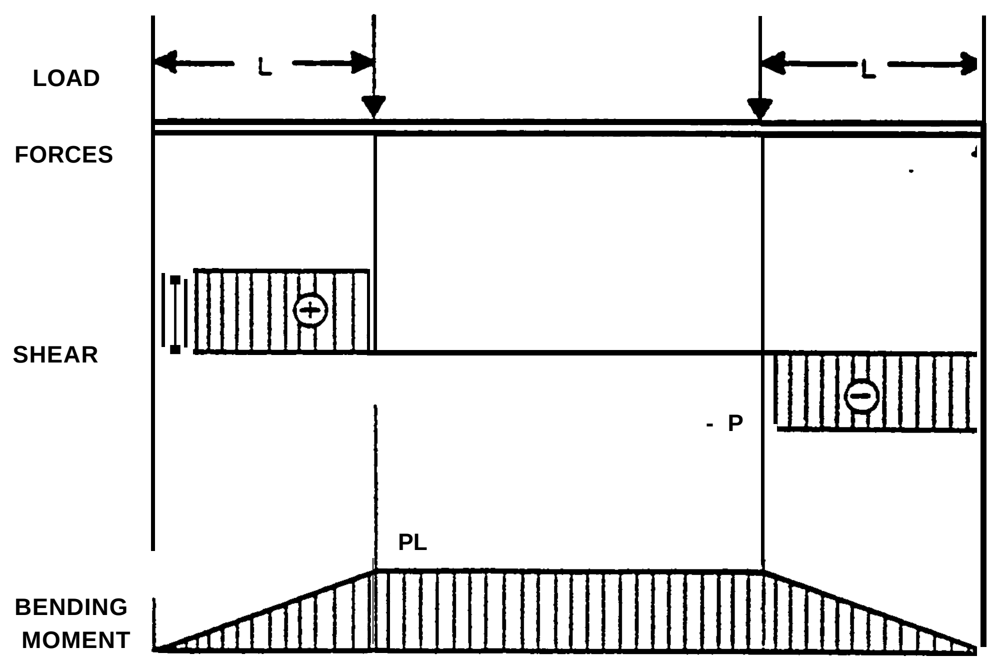
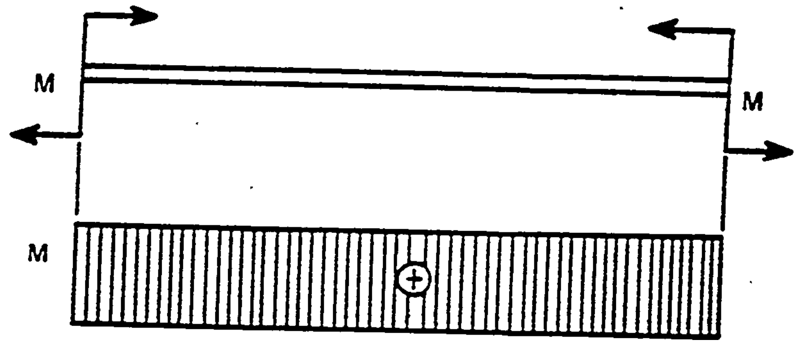
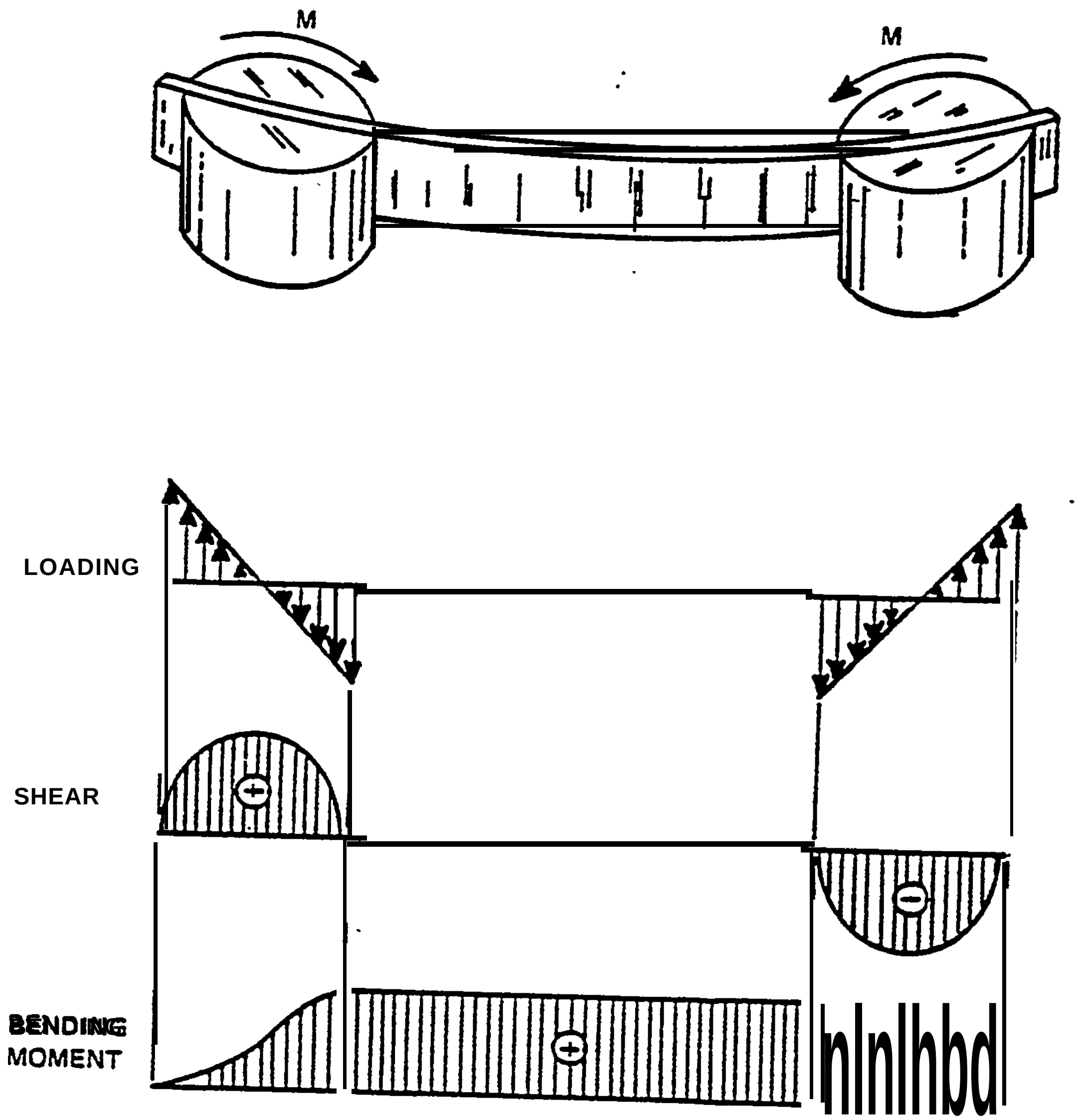


Figure 8. Four-Point Bending



a) Idealized pure bending.



b) Realistic "Pure" bending.

Figure 9. Pure Moment Bending.

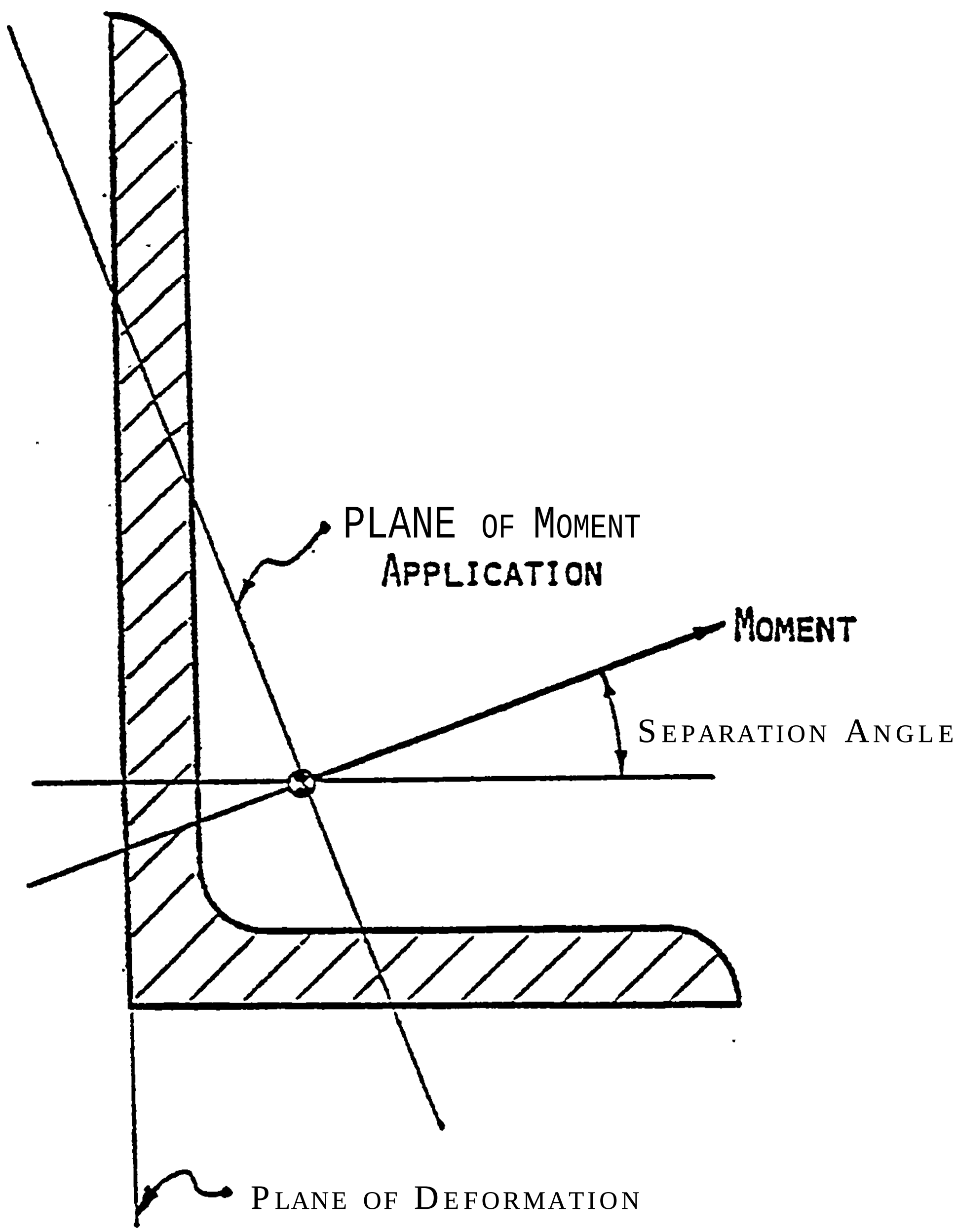


Figure 10. Separation Angle for an Angle *Cross* Section

benders do not have this capability they attempt to minmize out-of-plane deformation to asymmetrical cross section beams by clamping two or more beams together to form a composite member of symmetrical cross section. When unclamped, the forces change after bending, necessitating additional corrective action. This problem is amplified with NASSCO fabricated beams (see Figure 2). The Pullmax-Ursviken frame bender, manufactured in Sweden allows bending in two perpendicular planes so that out-of-plane deformation can be partially removed by a compensating bend; older benders require remounting of the beam (similar to the "Bulldozer") for the restoring bend. Common practice is to ignore it, as with hot slab cooling deformation, and rely on compensation during ship assembly (see Figure 6).

The unique feature of the Case Western bender is its self-adaptive operation, which directs the bending and uses computer controled feedback to continuosuly correct for springback. out-of-plane deformation could also be corrected by feedback, but this routine appears unnecessary since initial calculations of separation angles have proven adequate to effectively eliminate out-of-plane deformation. An operator can adjust the separation angle manually to correct any incipient out-of-plane deformation; however, such corrections have not been necessary on beams (including a symmetrical) bent in the laboratory.

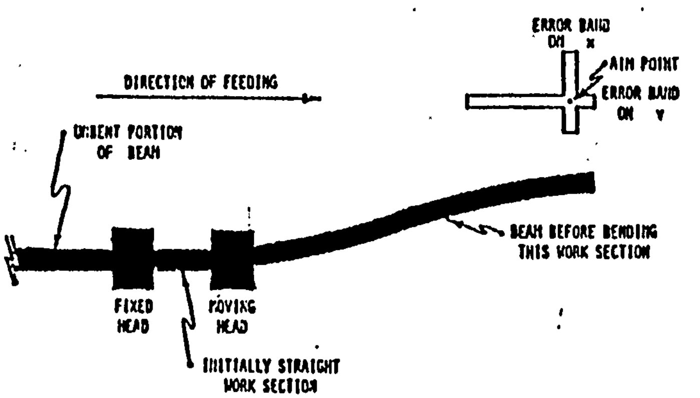
The present computer routines: (1) compute the desired position of the end point of the beam; (2) drive the end point to its proper 'y" coordinate, including a springback correction that is checked after each bend: and (3) once the "y" position is satisfactory, translate the beam end to the desired "x" position.

These actions are summarized in the plan views of Figure 11. The bending moment to any beam is applied by two gripping heads, one of which is fixed and the other of which is movable (the section to the right of the gripping heads of the example has already been bent). All new bending takes place along tie straight section between fixed and moving heads (as in Figure 11A) . Two displacement transducers are mounted on the dot at the end of the beam to read out the (x, y) coordinates of that position. The computer calculates the desired position of the dot after bending--the aim point. The computer then directs an overbend (Figure lIB) and if, after springback, the "y" position is not satisfactory, it may require the calculation of a revised springback correction. This is repeated until the "y" position is satisfactory, at which time the feed mechanism advances the beam to the desired ""x" position.

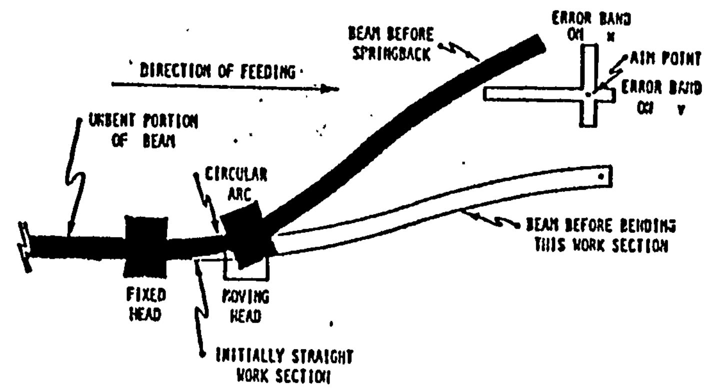
The result is a machine that incorporates state-of-the art computer technology to upgrade the beam-bending operation to a faster, more accurate process free of many previously unavoidable human errors. Concurrently,the machine employees principles of mechanics made practical by improved electronic control, that produce a structurally superior bend.

DESIGN OBJECTIVE OF THE CNC FRAME BENDER AT NASSCO

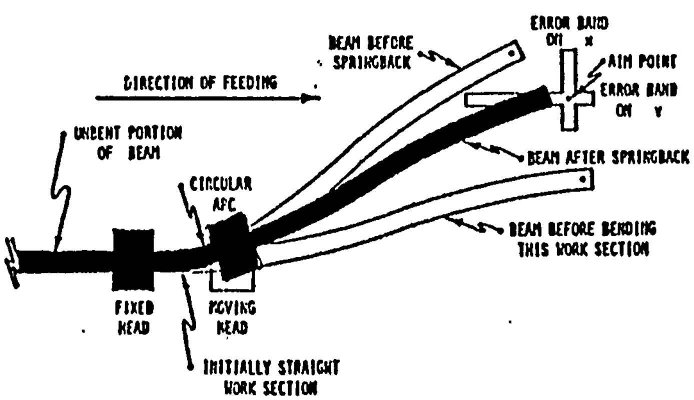
The CNC frame bender will be designed for (1) straightening of rolled or fabricated sections to remove distortion due to fabrication or storage and (2) cold bending of frames in a



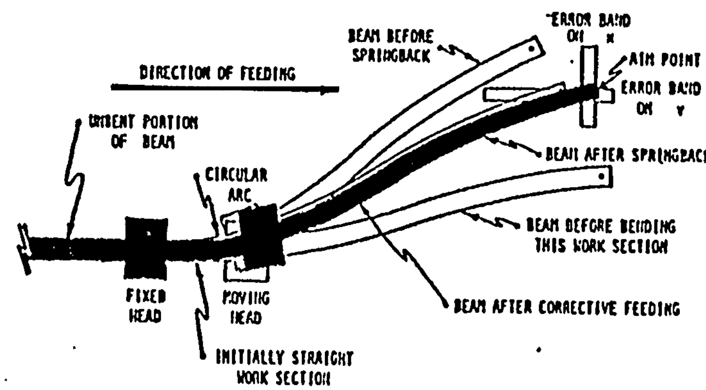
(a)--Initially Straight Work Section



b)--Bend Including Springback Estimate



(c)--Springback within Error Band on Y



(d)--After Corrective Feeding to Aim Point

Figure 11 --Processing of a Single Work Section

single plane with the flanged section either in tension or compression. The straightening function will be handled by a "canned" program hard-wired in the machine's computer, thus requiring no input data for the straightening of beams. In addition to straightening in the bending (horizontal) planes, the CNC frame bender will also be capable of straightening in the vertical, plane. In addition, a means of correcting for distortion due to twist in the frames will be investigated and, if practical, included in the design of the first CNC frame bender.

The CNC frame bender will handle angle or T-shapes as well as asymmetrical sections up to 25 inches deep having a web thickness up to three quarters of an inch. It will bend the larger frames to a minimum radius of 40 feet; smaller frames, down to approximately 8 inches deep, will be bent to smaller radii. However, the maximum bend (minimum radius) will be kept within the limits of the runout table. The minimum bend radius for 8 inch sections will be 7 feet. The maximum length of the beams will be 42 ft. Overall accuracy objective will be & inch with three iterations.

The production rate of the machine will be a minimum of four (4) 42 ft. long frames per hour and the straightening rate will be eight (8) frames per hour. The frame bender will be designed for minimum operator attention. Ideally, no actions will need to be taken by the operator other than setting up for any particular section, loading the beam, activating the machine, and removing the beam after it has passed. entirely through the frame bender. The machine will conform to reasonable shipyard safety requirements with electrical equipment suitable for protected outdoor environment.

As currently evisioned, the CNC bending machine's devices and subsystems can be generally listed as follows:

1. A beam feeding device.
2. A fixed head including the clamping and die devices.
3. A stabilization device.
4. A beam marking system. (The extent of marking capability will be determined by practicality and cost).
5. A movable head including the clamping and die devices and main power cylinders.
6. A bending table including pivot mechanism, track and drive system for x-axis movement of the movable head and power cylinder mechanism for the z-axis movement.
7. A runout table including x-y positon indicators and air cushion pedestals with locking and unlocking features.
8. A central hydraulic system including automatic and manual valves and controls.
9. A computer director system including all electrical and electro-hydraulic interface equipment.

PRINCIPLE OF OPERATION OF THE CNC FRAME BENDERAT NASSCO

The beam is fed into the machine through a fixed head containing a die and clamping mechanism, using a variable clamping distance dependent on the size of the beam to be processed and the amount of force required. The feeding-system is to be positioned at the input side of the fixed head, as well as the output side of the movable head so that a new beam can be automatically moved into the machine and a finished beam completely removed. A pneumatic or hydraulic center punch marking system will be incorporated at the discharge end of the fixed head. If practical the marking system will be capable of transversing along the y-axis so that the end cut of the beam can be punched, as well as suche other reference marks as the water line on transverse beams.

The beam will be fed from the fixed head to a similar movable head with an identical clamping system. If practical, a stabilization system will be included between the fixed and movable heads, clamping the extreme end of the beam web along its length in order to prevent buckling of the beam when the flange is bent to a convex configuration. The distance between the fixed and movable heads will be variable; however, it will be fixed for any one beam or (preferably) for any series of beams. The machine and *the* input data will be designed to allow for the largest possible work section in order to have the highest production rate on the machine. Inflection points will be designed out of the beam model as far as possible by the shipyard's own computer program. Also, full advantage will be taken of any straight sections by keeping them at the ends of the beams to avoid wasting of the ends that must be held by the clamping mechanism.

The movable head will be actuated by two double-acting power cylinders anchored one upstream and one downstream of the movable head. Bending of the beam is accomplished by first clamping the beam with the fixed head, then clamping with the movable head and applying a moment, using the two power cylinders, to the moving head which has freedom to rotate about a radius from the inside end of the fixed head clamp.

In the case of non-symmetrical sections the out-of-plane distortion will be calculated from the known geometry of the section and automatically compensated for by a third cylinder acting in the vertical direction as described below. The normal procedure for bending is identical to that described in the reports prepared by Case Western Reserve University. The movable head, beam feeding device, marking device, run-out table, and main power cylinders will be mounted on a common rigid base plate. This base plate will be free to pivot about a point in line with the inside end of the fixed head clamp. The vertical power cylinder, mentioned above will be attached to the downstream end of this bed and in the relaxed condition will allow the bed to move either up or down as determined by the out-of-plane deformation of the beam. The compensating force will be applied automatically and concurrently with the bending forces thus assuring that the final bent beam remains in a single flat condition.

During straightening operations, the beam will be fed into the frame bender in an identical manner as previously described and automatically bent to return it to a straight line. At this time, the vertical power cylinder can be used to correct any distortion in the vertical plane.

A run-out table will be provided on the discharge side of the frame bender. The dimensions of the run-out table will be a maximum of 20 ft. wide by 42 ft. to allow bending of the beam in either direction from the centerline of the bender to a maximum y-axis displacement of 10 feet to either side. The run-out table will consist of a simple frame supporting the mechanism for accurately determining the end position of the beam in the x-y plane. This position indicator will be of the optical, transducer or mechanical linkage type. It will be protected, insofar as possible, from damage that might be caused when removing the beam from the run-out area. The beam will be supported by air casters, the number of casters required being dependent on the length and weight of the beam. These casters will be supported by the run-out table and stacked at the discharge end of the movable head, then will automatically clamp onto the beam at predetermined points. These points will be determined either by the indexing mechanism of the frame bender itself or pre-determined on the input tape. The bearing clamping mechanism, as well as the air bearing supports, will be supplied with service air from the shipyards central system.

Power for the frame bender will be exclusively hydraulic except for the pneumatic power requried for the air casters. A packaged central hydraulic system will belocated on or adjacent to the frame bender and will provide hydraulic power for advancing the beam, adjusting the beam advance mechanism, clamping, stabilizations actuation of the horizontal and vertical power cylinders, and any other necessary functions on the bender. The position indicating equipment will be of the direct electric type.

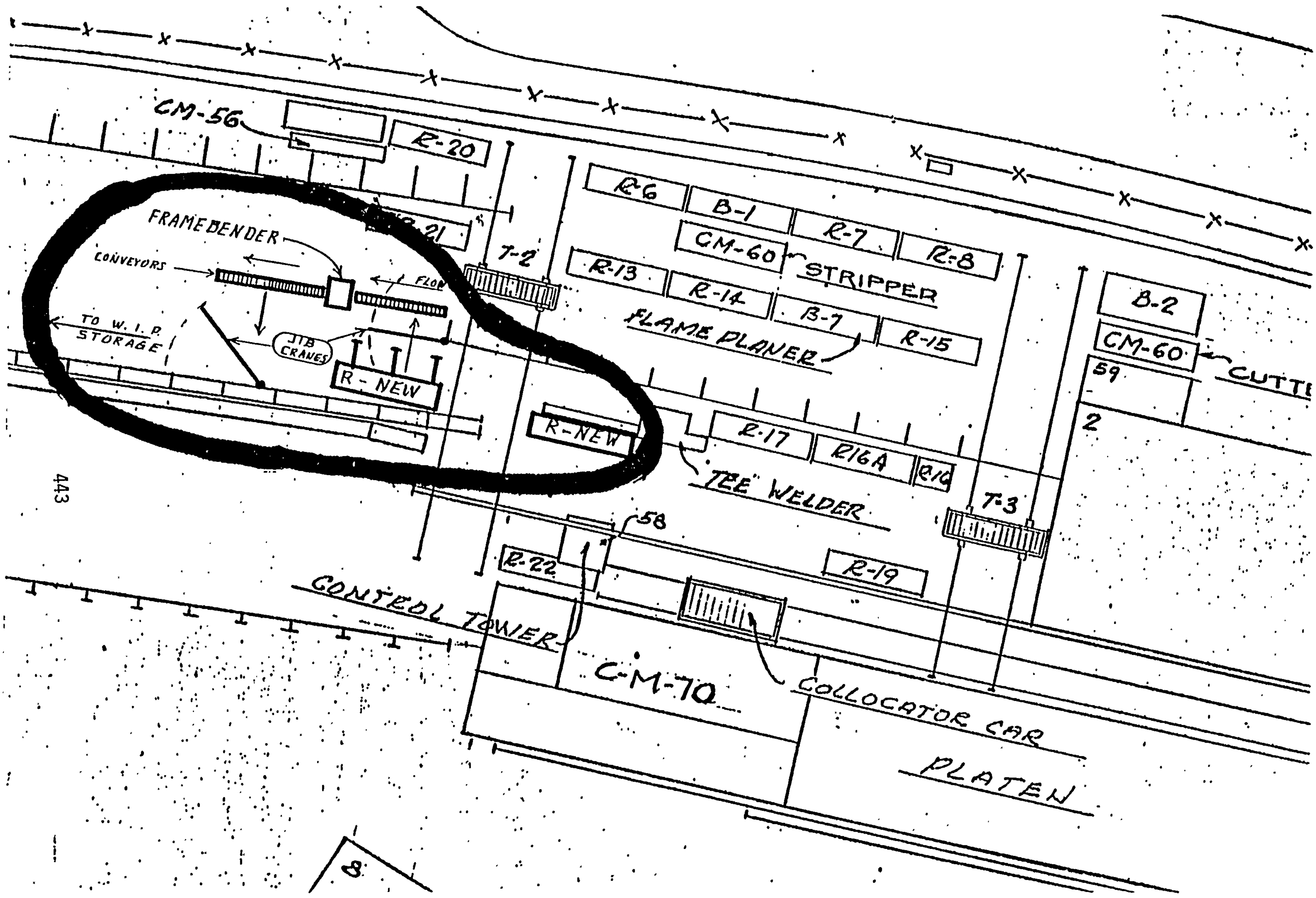
The computer hardware as well as the interface equipment will be chosen for its adaptability and suitability for the particular function involved; it will also have manual override controls so that the operator, if he wishes, may operate any mechanical function of the frame bender.

APPLICATION OF THE CNC FRAME BENDER AT NASSCO

Although the research and development of the CNC frame bender saw use of the AUTOKON program, the production model will have a "stand alone" mini-computer which will permit interface with most of the shipbuilding programs, including SPADES used at RASSCO. SPADES has a frame bending routine that makes template design or inverse curve and locates end cut. This routine will be modified to create paper tapes and incorporate the necessary interface to drive the CNC frame bender. For the purpose of checking and verification, beam design will continue to be produced on the drafting machine; the only change in NASSCO's lofting effort will be the elimination of templates.

The CNC frame bender will be inserted into the production line downstream of the tee beam welder (see Figure 12). The fabricated beams will be accumulated on a roller-conveyor adjacent to the run-off table of the tee beam welder, moved by transfer car (T-2) to another roller conveyor from which they are to be inspected; those beams requiring straightening will be passed through the frame bender and then to work *in* process (WIP) storage (by size); those beams not requiring straightening will be forwarded directly to WIP storage. As required by production schedules, beams will be withdrawn from WIP storage and routed either directly to the next operation or back to the frame bender for shaping, thence to the next operation. This will permit *larger*

TENTATIVE LAYOUT
FRAMEBENDER: INSTALLATION



production runs and random access order picking rather than the laborious system of storing and locating beams by individual part numbers or attempting to produce them as they are required. Such improvements in procedure can be made possible *only* because of the automation and production rate associated with the CNC frame bender.

APPENDIX

Reports and Publications

"Automation in Shipyards: First the Frame" (10 rein, 16MM sound color film produced for NSF/RANN by Image Associates, Wash., D.C.)

"Dear Factory: Make 100,000 Widgets," MOSAIC, Vol. 5, No. 4 (Fall 1974), pp. 2-8.

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