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TRANSFER PROGRAM (TTP)

SPECIAL REPORT
ACCURACY CONTROL PLANNING
FOR HULL CONSTRUCTION

Prepared By:

Levi ngston Shipbuilding Company
in cooperation with:
IHI Marine Technology Inc.

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PREFACE

This report is one of a series of detailed reports emanating from the Shipbuilding Technology Transfer Program performed by Livingston Shipbuilding Company under a contract with the U.S. Maritime Administration.

This report augments the Livingston Final Report on Quality Assurance, Number 2123-5.1-4-1, dated 3 March, 1980, with details concerning the planning functions carried out by Accuracy Control groups for hull construction within the shipyards of Ishikawajima-Harima Heavy Industries (IHI) of Japan.

In order to place the material contained herein within the overall Accuracy Control system reference to the above mentioned Final Report should be made.

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INTRODUCTION

This report presents details of the Ishikawajima-Harima Heavy Industries (IHI) Accuracy Control planning activities used in the IHI shipyards in Japan. The report deals specifically with the planning applicable to hull construction with only minimal reference to outfitting.

This report is one of several emanating from the Shipbuilding Technology Transfer Program performed by Livingston Shipbuilding Company under a cost sharing contract with the U.S. Maritime Administration.

The material contained herein was developed from the study of the Accuracy Control system presently in operation in the IHI shipyards in Japan. Information for this study was derived from source documentation supplied by IHI, information obtained directly from IHI consulting personnel assigned on-site at Livingston, and from personal observation by two teams of Livingston personnel of actual operations at various IHI shipyards in Japan.

Other reports pertinent to the subject of Accuracy Control and part of the Shipbuilding Technology Transfer Program are:

Livingston Final Report - Quality Assurance System

.Livingston Final Report - Industrial Relations

This report consists of seven sections as follows:

Section 1 - Accuracy Control Overview

Section 2 - Planning In Design

Section 3 - Vital Dimensions & Points of Accuracy

Section 4 - Scheme of Added Material

Section 5 - Base Lines

Section 6 - Tolerance Standards

Section 7 - Conclusion

It should be noted that this report deals with Production Planning entirely from the viewpoint of Accuracy Control. In reality, Production Planning takes into consideration many more aspects of engineering such as: maximum utilization of facilities and manpower, productivity, safety improvement and so on. This is not intended to be a complete description of the Production Planning process.

SECTION 1

ACCURACY CONTROL OVERVIEW

Accuracy Control in IHI is the underlying concept of the entire production **system**. The concept is simple in its definition but highly involved **and** complex in **application**. The objectives of Accuracy **Control are**: to maintain the highest accuracy possible at each stage of production of every fabricated **piece, part, sub-assembly**, assembly and erected **unit**; to minimize the work at the erection **stage**; and to continuously improve the production process to yield the highest accuracy in **all products**.

The Accuracy **Control** function comprises three **elements: Planning; Field Activity; and Data Analysis and Information Feedback**. Each of these activities is carried **out** by several **different** groups located in different **departments**: the Shipyard Design **Department**, the-Panel **Workshop**, the Hull Workshop and the Fitting **Workshop**. These Accuracy Control groups report to the managers or superintendents of their respective departments or **workshops**.

The activities of these various groups are started well in **advance** of the development of working **drawings**. Accuracy Control Planning is undertaken on the basis of **preliminary (basic)** design (which is generated by the IHI Head Office in **Tokyo**) several months prior to the start of **fabrication**. This planning effort **involves** participation with the designers in determining the ship **breakdown**, the fabrication **sequence**, the assembly **sequence**, and the erection **sequence**. Subsequently, Accuracy Control Planners **develop: Vital Dimensions and**

Points of Accuracy; the Scheme of Added Materials; Base Lines for lofting and measuring; and Tolerance Standards for the ship being planned.

Subsequent to the completion of the Accuracy Control Planning and to the start of fabrication, Accuracy Control Field Activities begin. These activities consist of development of: check sheets for fabricated pieces, sub-assemblies, assemblies, and erected units; template and plate layout requirements; methods for cutting and measurement of plates; and fabrication methods. Actual field measurements are then taken on the manufactured pieces and assemblies by workers, Accuracy Control personnel and Quality Control personnel in accordance with the check sheet requirements. Through this process data are collected for subsequent analysis and information feedback to design or production groups.

The data collected by Accuracy Control groups are analyzed to determine causes of errors or material discrepancy (i.e. distortion, warpage, twist, etc.) and resultant information is fed-back to the appropriate organization for correction either in design or in the production process responsible for the error or discrepancy.

Throughout this Accuracy Control process every attempt is made to improve the production processes, methods and techniques. to yield better, more accurate products at each production stage. This results not only in improved quality but also in increased productivity throughout the ship construction process.

SECTION 2

PLANNING IN DESIGN

2.1 GENERAL

Accuracy Control planning begins immediately upon completion of the Basic Design (accomplished by the Design Department in the Head Office of IHI in Tokyo). The Basic Design consists of: Unfaired Ship's Lines, Midship Section, Construction Profile, General Arrangement and Machinery Arrangement drawings. On the basis of these plans the shipyard Design Department and the Accuracy Control group in the Design Department undertake the breakdown of the ship into "Blocks" or assembly units. This activity is called "Hull Block Planning" and consists of dividing the ship into manageable units suitable for assembly and erection.

Subsequent to this initial planning step "Block Assembly Planning" is begun. This activity consists of a further breakdown of each "Block" into its component pieces. As each block is disassembled on paper Accuracy Control Engineers study and identify critical dimensions and points for measuring the accuracy of each component part and the entire assembly.

Also during this process the erection sequence is determined based on the Hull Block Planning and the assembly sequence is determined as a result of the Block Assembly Planning. As each assembly is planned, fabrication requirements for each component and sub-assembly are determined. Standard pieces are identified for routine processing whereas peculiar or non-standard pieces are identified for

special Accuracy Control consideration, planning and measurement.

During this design planning phase Accuracy Control requirements are developed for all purchased material and sub-contracted components. These requirements are included in procurement specifications.

As the Block Assembly Planning is completed Assembly Specification Plans are developed detailing methods of assembly and erection of each unit. Workshop inputs provide details of welding processes, welding edge beveling, extra lengths required for butt lines, and similar information for inclusion in the Specification Plans.

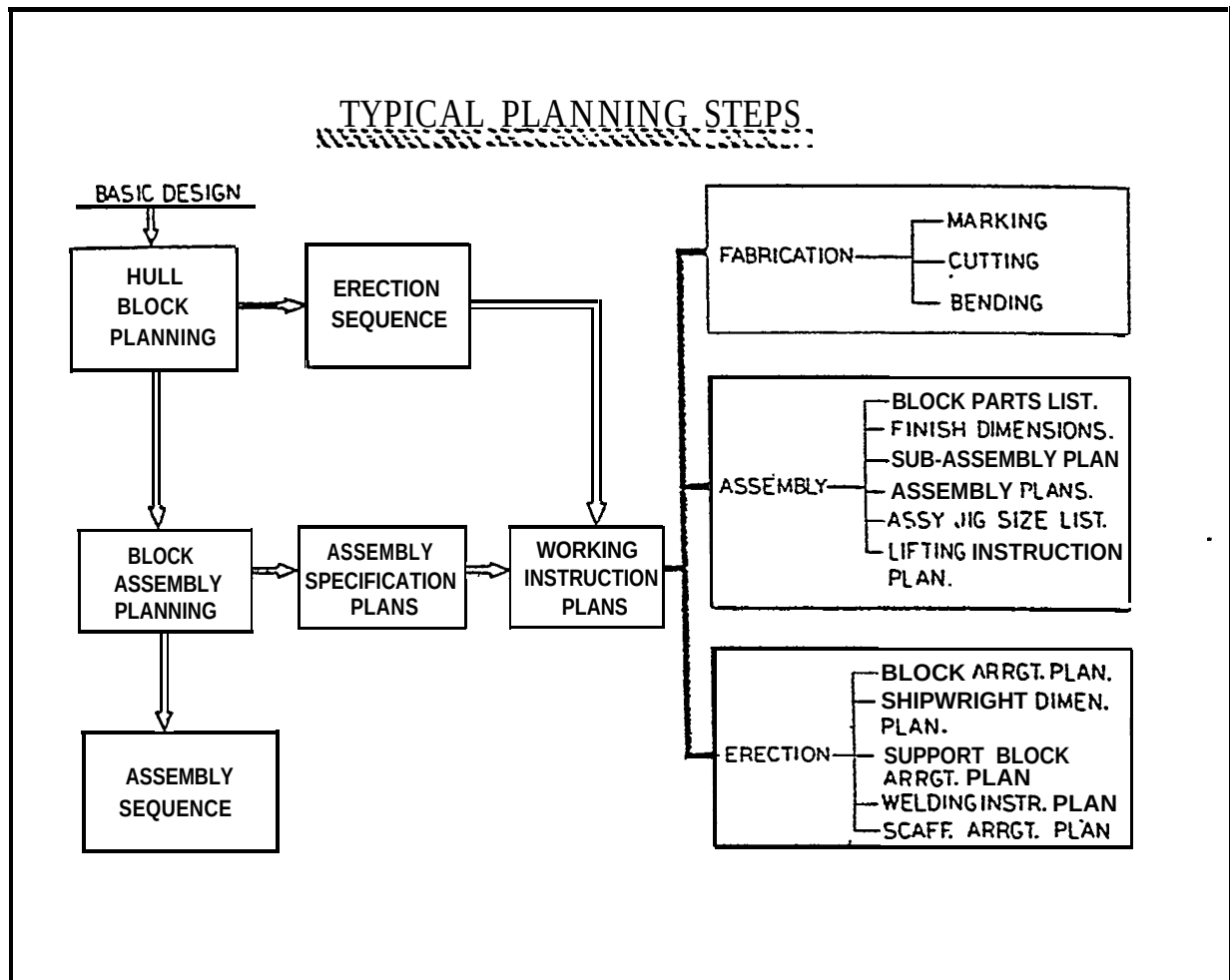


FIGURE 2-1

Detail Assembly Specification Plans are then reduced to Working Instruction Plans which prescribe the processes, methods, and techniques to be used for fabrication, sub-assembly, assembly and erection of each piece, component and unit. Figure 2-1 depicts the development of these various plans.

The following pages describe each of the above plans and the role of Accuracy Control groups in their development.

2.2 HULL BLOCKING PLAN

The Hull Blocking Plan is the initial activity to be performed by the shipyard Design Department. This activity comprises the breakdown of the ship into individual units capable of being designed, produced, handled, and erected in the most efficient and least costly manner.

Because of the many years of experience with this method in IHI the ship breakdown is a routine and systematized operation. Planning generally centers initially around the mid-ship sections (i.e. cargo holds) since these sections represent the majority of ship units and because of the repetitive nature of the mid-ship section units or blocks. The bottom assemblies of these cargo hold sections are also the starting point for the development of accuracy control requirements for curved (bottom) assemblies.

Forward and aft sections of the ship are necessarily treated individually and require a more indepth analysis to determine proper division into assembly units.

Beginning with the bottom mid-ship section of the ship, assembly units are defined using the following criteria:

- 1) First block (unit) to be laid in the building basin (this

is generally the mid-ship section just forward of the engine room).

2) Crane Capacity - The size of the blocks must be restricted to the lifting capacity of the available cranes both in the assembly areas and in the erection area.

3) Assembly Areas - Block size is further limited by the size of the assembly areas and facilities such as over-turning equipment, transporters, cranes, etc. During over-turning and transportation the unit size must not be so great that deformation will occur during lifting or movement.

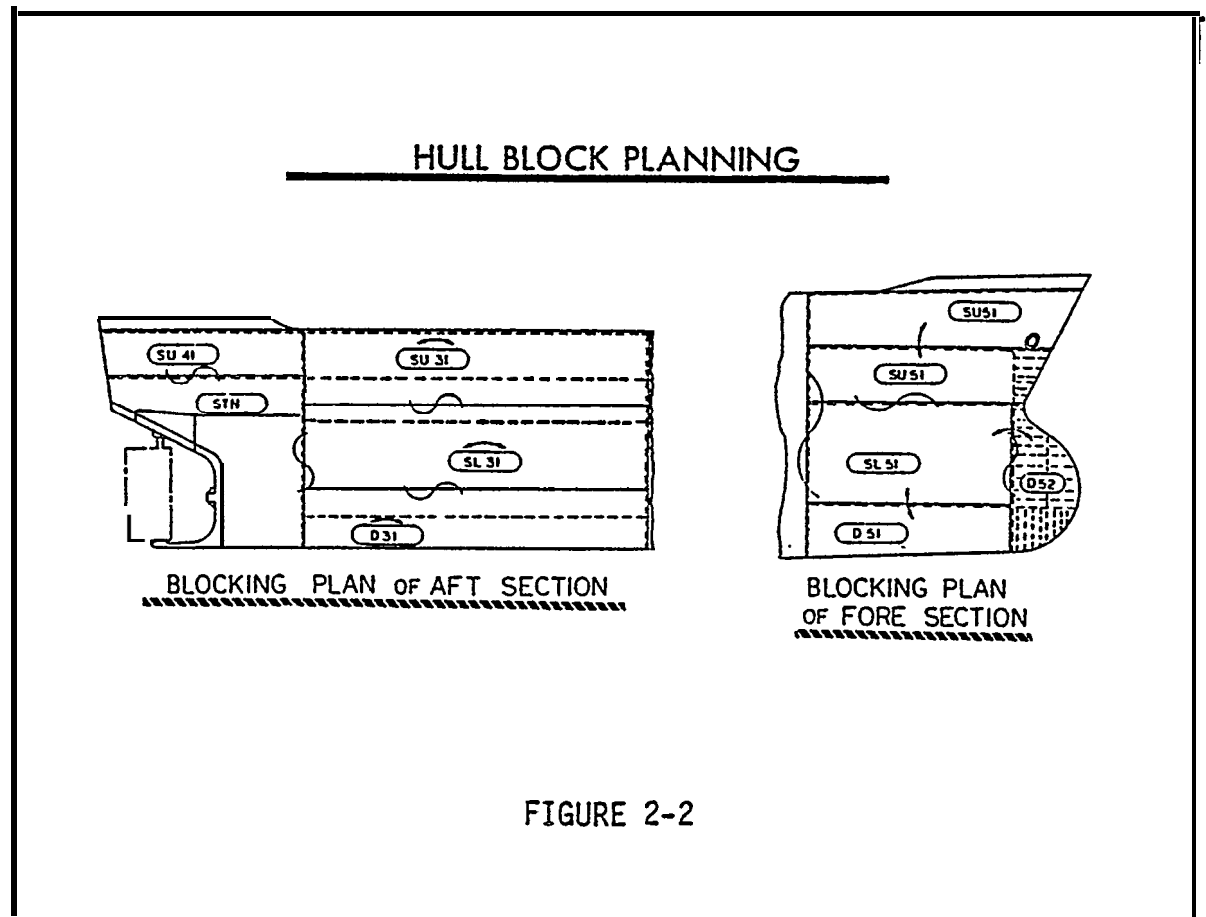
4) Work Flow - Block size should be kept at an optimum size to provide maximum work flow through the production work stations. Too big a block would require a prolonged assembly time thus creating a "bottle-neck" for following work.

5) Reduction of Erection Work - Block size and shape must be capable of being easily erected and must be stable during joining. Welding lengths must be minimal, especially difficult (overhead) welding.

6) On-block Outfitting - Assembly and outfitting schedules must be taken into consideration in sizing blocks. Blocks of too large a size or requiring an inordinate amount of on-block outfitting will cause schedule delays, consume assembly area space, and delay following work (which may also result in idle time in following work stations).

Using the above criteria the ship is divided into manageable blocks which fit the facilities, equipment, manpower, and schedules established for ship construction. The overriding concern during this

planning step is to derive the highest productivity at the stages of assembly and erection, and to maintain the highest accuracy of the manufactured units. Figure 2-2 presents an example of ship hull sections divided into blocks by the above process.



2.3 ERECTION SEQUENCE

An integral part of the Hull Block Planning is the development of the Erection sequence. In the calculation of the size and weight of the erection blocks the sequence of laying the blocks into the building basin and of assembling the blocks one on top of the other is determined.

2.4 BLOCK ASSEMBLY PLANNING

After division of the ship into manageable blocks, typical common-shaped blocks are analytically disassembled (on paper) in a progressive breakdown from the entire unit to the component sub-assemblies and then to the parts and pieces which constitute the sub-assemblies. All unique blocks are broken down in this manner. Figure 2-3 shows a typical example of such a breakdown.

These breakdowns serve several purposes in addition to showing the basic assembly sequence of each block. A preliminary evaluation of the assembly sequence yields details concerned with the necessary facilities and processes required for the assembly, e.g. required fitting jigs, probable welding processes, required assembly area size and capacity. Further details are developed including: the classification of sub-assemblies and assemblies; reference level and line; length and types of welding-joints; welding edge-preparation requirements; and requirements for added material for adjusting seam and butt lines.

All of this planning is considered "preliminary" information for the development of "detailed process planning" which is documented and disseminated as "Assembly Specification Plans" and "Working Instruction Plans".

2.5 ASSEMBLY SPECIFICATION PLANS

Based on the information developed during the "preliminary process planning", formal Assembly Specification Plans are developed. These plans detail the methods to be followed during fabrication, assembly and erection. This planning is accomplished by engineering personnel and accuracy control engineers in the Design Department and

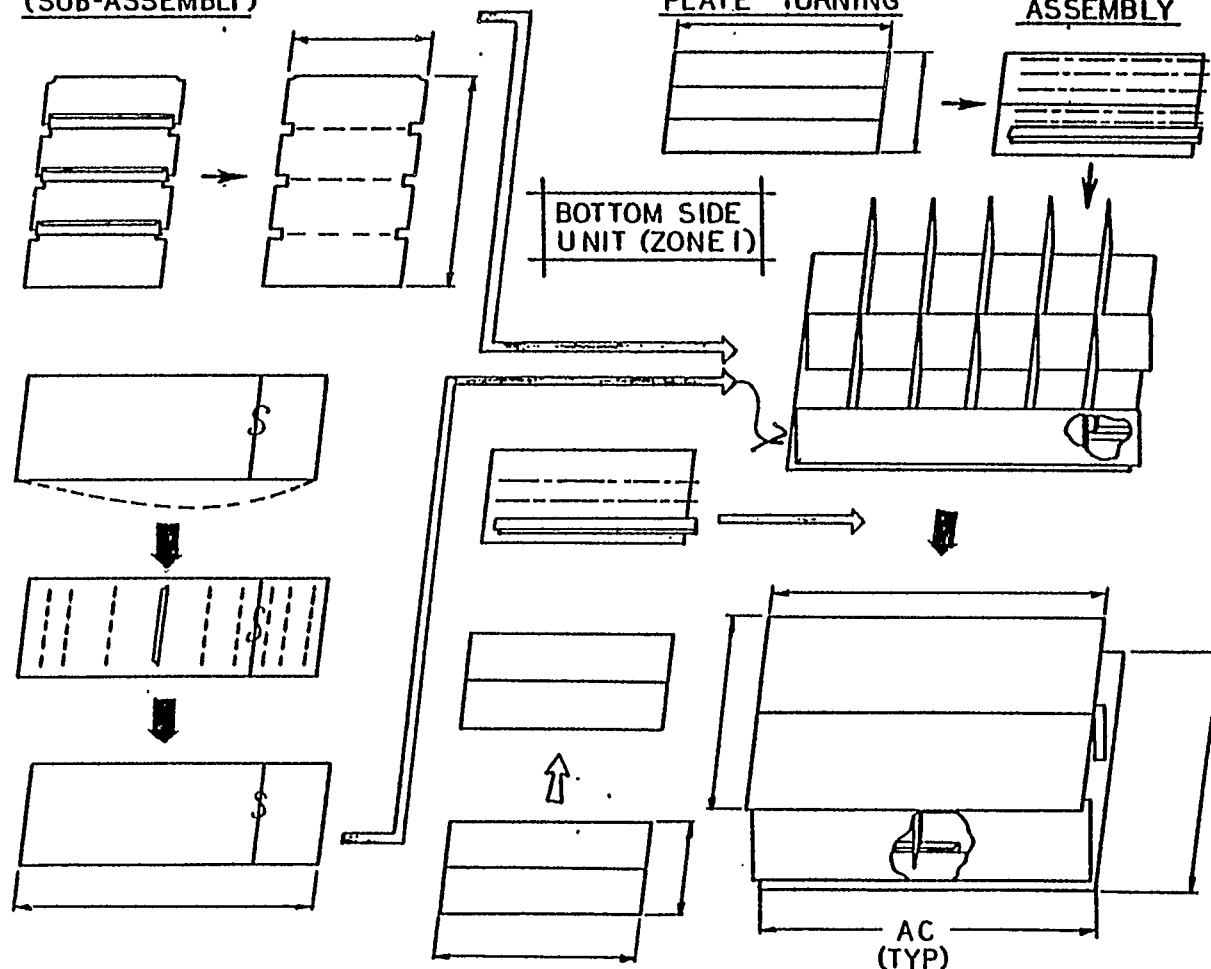
BLOCK ASSEMBLY PLAN 'example'

FABRICATION SEQUENCE

(SUB-ASSEMBLY)

PLATE TURNING

ASSEMBLY



Handwritten notes:
 1. 2K top
 2. 2K top
 3. 2K top
 4. 2K top

FIGURE 2-3

in the various **workshops**.

Assembly Specification Plans are prepared for **blocks** of the fore and aft **sections** of the ship and for typical mid-ship (**cargo holds**) **sections**. Evaluation of **the** assembly sequence is made to determine the assembly process lanes which must be used for curved versus flat **blocks**. This evaluation concerns an in-depth analysis of the processes through which each of the piece parts and the sub-assemblies must flow in order to be collected and assembled in the least **possible** time while simultaneously achieving full utilization of **manpower**, facilities and **equipment**. Throughout this **planning**, attention is given to the maintenance of accuracy at every production stage and **sub-stage**. Figure 2-4 is an example of the Assembly Specification Plan prepared at this **stage**.

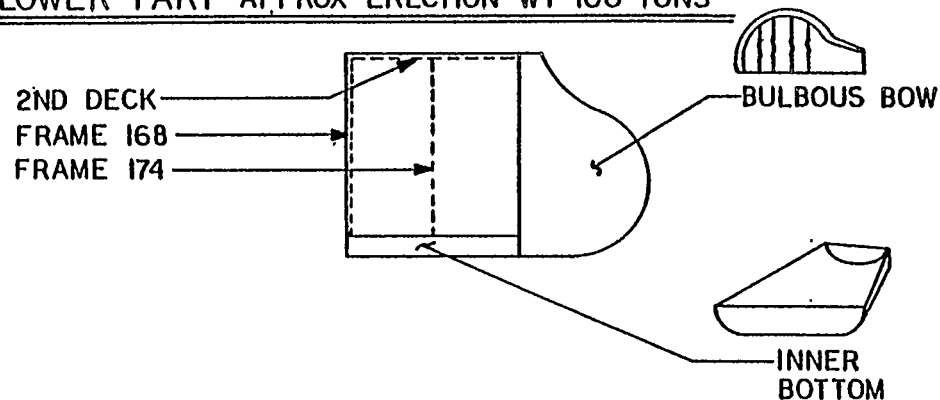
The planning accomplished during the preparation of the **Assembly Specification Plans** provides progressively more detailed information for lower-level planning in the workshops. From this relatively broad planning for assembly of **blocks**, Detailed Assembly Specification Plans are developed for each **block**. These plans provide more precise **assembly** procedures to be utilized by the workshop **personnel**.

The detailed plans specifically identify the assembly area to be utilized and the methods and processes to be **used**, such **as: setting** of **jigs**; joining of **plates**; marking of **plates**; the sequence of **assembly**; accuracy check points to be measured at each step in the assembly **process**; **on-block outfitting**; painting **requirements**; and performance control parameters (**e.g. weld deposit per hour**) and manhour forecasts for each **block**.

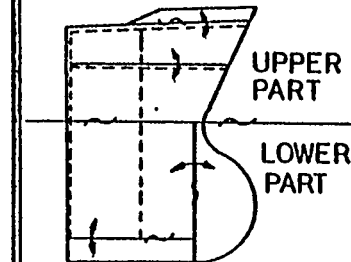
Preliminary Assembly Specification Plan

FORE BLOCK UNITS TO BE ASSEMBLED

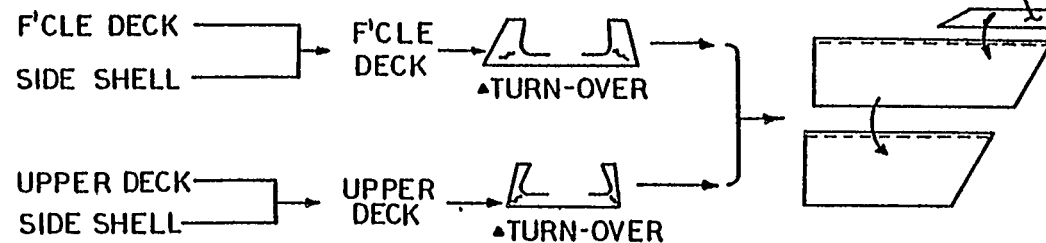
LOWER PART - APPROX ERECTION WT 100 TONS



FORE BLOCK ASSEMBLED



UPPER PART - APPROX ERECTION WT. 120 TONS



NOTE:▲ THESE BLOCKS TO BE ASSEMBLED AS CONDITIONS PERMIT AT THE PRE-ERECTION STAGE.

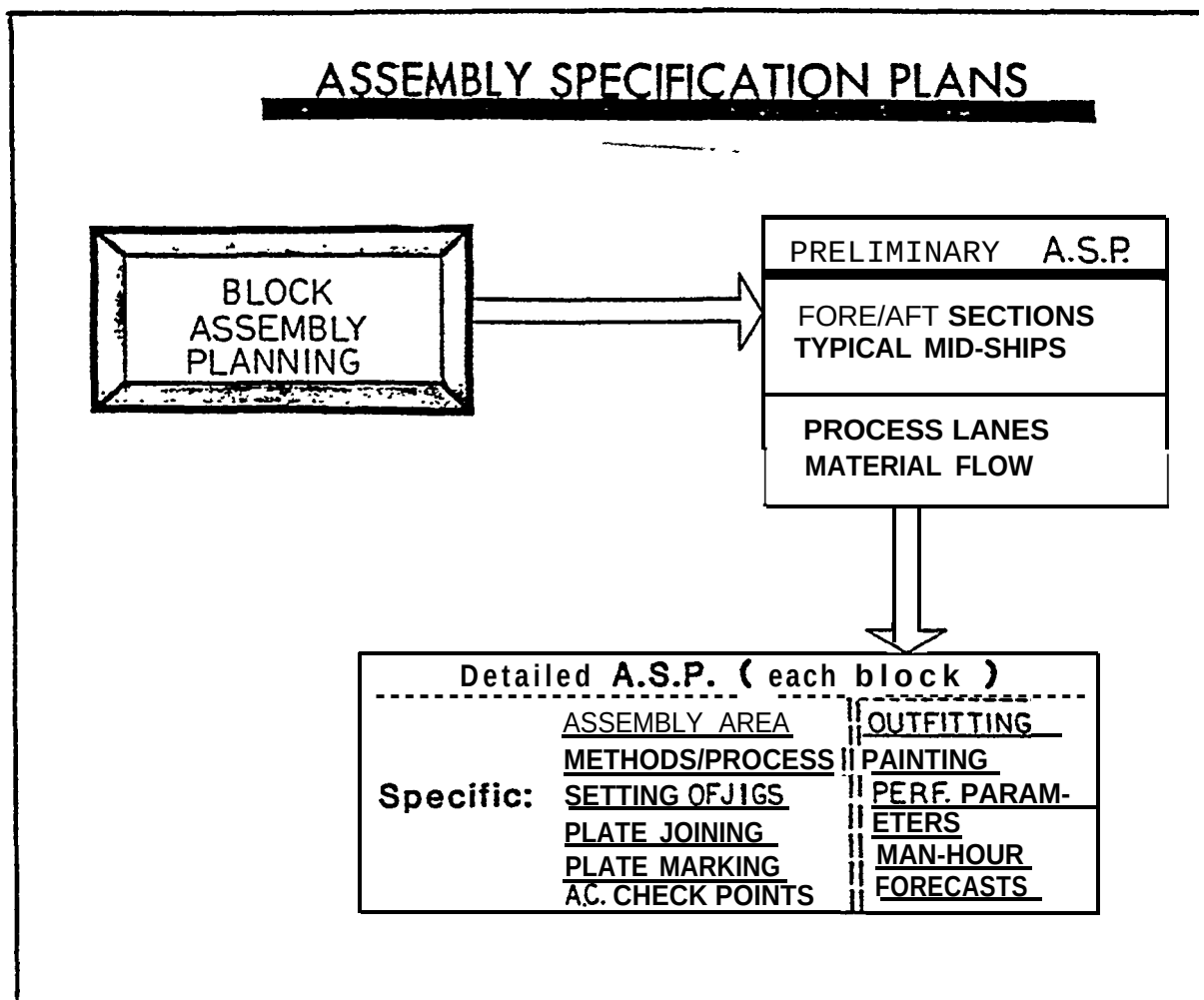


FIGURE 2-5

These detailed plans provide the information for development of still lower-level detail contained in Working Instruction Plans. Figure 2-6 shows an example of these Detailed Assembly Specification Plans.

Detailed Assy. Specification Plan

Block	GSL31	ZD31-SL31	WT	TOTAL 58 TONS
	GSL32	ZD32-SL32	DM	2D31 --- 403

Isometric view of the assembly showing dimensions and components. Dimensions include 18m, 18m 500, and 3m 500. A central vertical line is labeled 'C'. Components are labeled as ZD51T SUB-ASSY, SL31 ZD31, SL32 ZD32, and SL31 & SL32.

Steps	Assembly Process		ACCURACY CHECK Points
JIG SETTING	ZD31&ZD32 HORIZONTAL JIG	SL31 & SL32 FIXED POINT JIG	HORIZONTALLY
PLATE JOINTING (ALL FAB. WELDING)			ASSY. REFERENCE LINE BEAM--C TRANS-FLAT LONG GIR ZD32 BUTT ZD32 LENGTH BETWEEN BUTT LINE. & WEB
MARKING	ZD31 P/S ZD32 FINISH DIMEN. PLAN	SD31 & 32 BATTEN	
ASSEMBLY	ZD31-32 P/S EACH SL31-32 ASSY EACH SIDE PRE-ERECTION PRE-ERECTION FLAT BASE ZD31 FITTING PARTS ON FLAT BASE		
CONTROL INDEX	WL-AUTO 90IM 288M		NONE
MAN-HOUR	ZD31-32 250 HRS.	SL31-32 420 HRS.	GS31-32 250 HRS.

FIGURE 2-6

2.6 WORKING INSTRUCTION PLANS

Working Instruction **Plans**, which represent the final planning **step**, are derived from the Detailed **Assembly** Specification Plans for each **block**. Working Instruction Plans provide detail working-level data for the **fabrication**, assembly and erection of each erection **unit**. These plans complete the development of data from the design **level** information to the working level details necessary for workshop **execution**.

Three Working Instruction Plans are prepared for each block in the area of **fabrication**: Marking **Plan**, Cutting Plan and Bending Plan (often the Marking and Cutting Plans will be combined into a single **plan**).

In the area of **assembly**, six plans are prepared on each block as **follows**:

- Block Parts Lists
- Finishing Dimensions Plan
- Sub-assembly Plans
- Assembly Plans
- Assembly Jig Size Lists
- Lifting Instructions Plan

Working Instruction Plans originated for erection **include**:

- Block Arrangements Plan
- Shipwright** Dimensions Plan
- Support Block Arrangements **P**lan
- Welding Instructions Plan
- Scaffolding Arrangements Plan

WORKING INSTRUCTION PLANS

Fabrication

MARKING
CUTTING
BENDING

Assembly

- BLOCK PARTS LIST
- FINISH DIMEN. PLAN
- SUB-ASSEMBLY PLAN
- ASSEMBLY PLAN
- ASSEMBLY JIG SIZE LIST
- LIFTING INSTR. PLAN

Erection

BLOCK ARRGT. PLAN
SHIPWRIGHT DIMEN.
P L A N
SUPT. BLOCK ARRGT
PLAN
WELDING INSTR PLAN
SCAFFOLDING ARRGT
PLAN

FIGURE 2-7

These plans provide all necessary information at each production stage for the proper manufacture of the respective block. The basic objectives intended for these plans are: 1) to effect control of the

total workload and the products as the work progresses through the various **process lanes**, sub-stages and stages of the production **system**; 2) to effect **control** of the great number of parts and **pieces** of material as they flow through the production **processes**; and 3) to provide explicit instructions to **all levels** of personnel concerned with the **fabrication**, assembly and erection of ship **components**.

Throughout this entire planning process Accuracy **Control** Engineers prescribe necessary requirements to obtain the highest accuracy in each fabricated **part**, sub-assembly and **assembly**.

SECTION 3

VITAL DIMENSIONS & POINTS OF ACCURACY

3.1 GENERAL

Throughout the planning effort described in the preceding **section**, Accuracy Control Engineers are developing detailed data concerning the vital dimensions and points of measurement to assure that **each piece part**, sub-assembly and assembly meets the highest accuracy standards **possible**. In **addition**, these engineers develop a plan (**scheme**) for providing added material at each stage of production to assure that errors can be corrected without **re-work** of the part and to provide for neat cutting at the various **sub-assembly**, assembly or erection **stages**. Accuracy Control Engineers also define the base lines which must be used for sub-assembly and unit alignment to keep maximum accuracy throughout the **production**, assembly and erection **processes**, and the **tolerance standards** to be observed by designers and production workers during **design**, ship component manufacture and ship **construction**.

All of these data are developed simultaneously with the basic ship production planning and are included both in the planning data and in the working "**Yard Plans**" (drawings) developed by the Design **Department**.

The **development** of the planning **data**, described in this and the preceding **section**, is an iterative process involving **detail** analysis and evaluation of the requirements of each individual **block**. In order to accomplish this planning the "**Basic Design**" drawings are required together with several drawings created by the shipyard Design Department,

such as: **scaled body plans, shell expansion,** and certain structural section plans. Also, the Blocking Plan, the Block Assembly Plan and the Erection Sequence is required prior to the start of this subsequent planning.

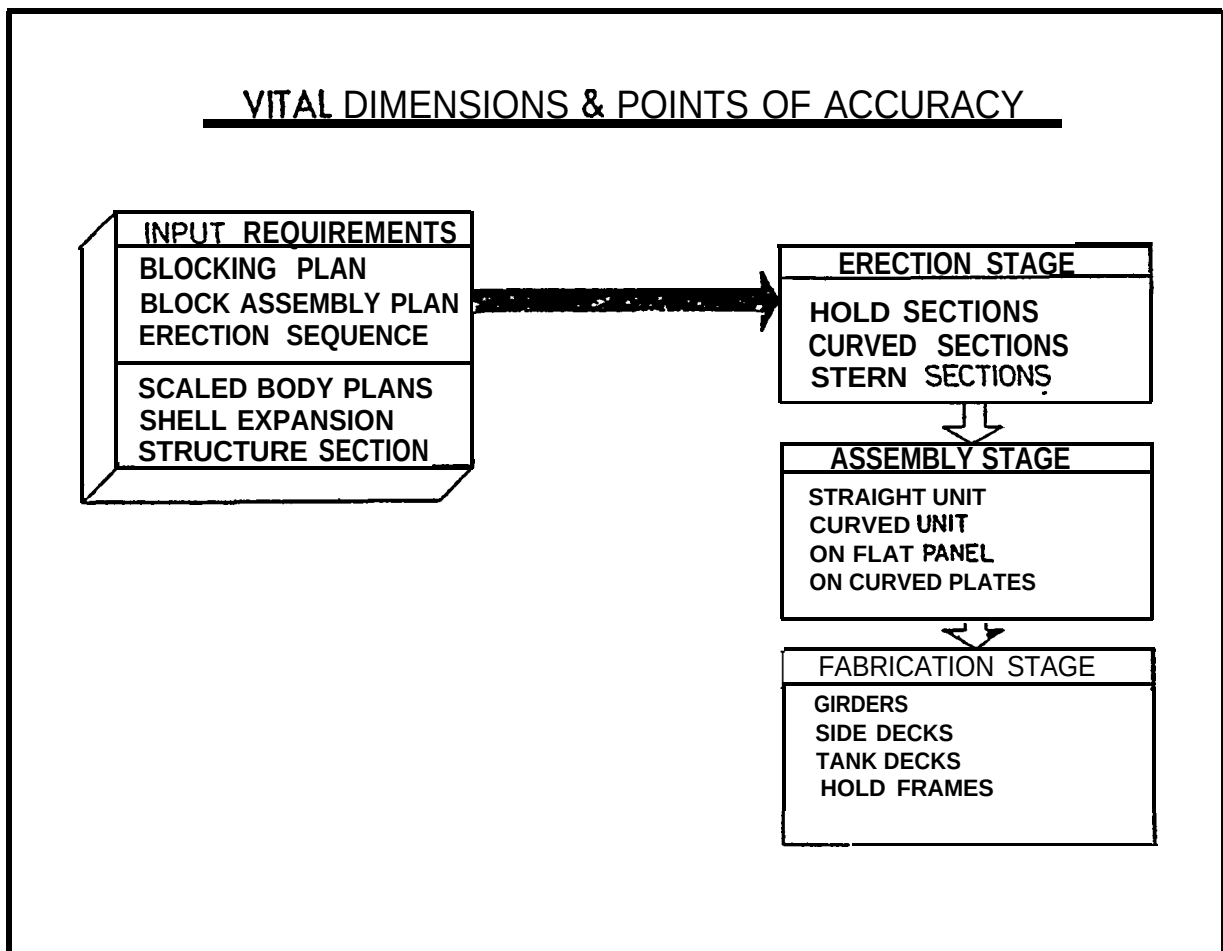


FIGURE 3-1

This section deals with the determination of Vital Dimensions and Points of Accuracy. Subsequent sections detail the other Accuracy Control planning responsibilities.

The planning for the vital dimensions and points of measurement concerns the three stages of Erection, Assembly and Fabrication in that order. All of the IHI planning proceeds from the end product (i.e. the erected ship) back to the assembly and thence to the sub-assembly and the piece parts. Therefore, the vital dimensions and vital points of accuracy are first determined at the Erection stage.

3.2 ERECTION STAGE PLANNING OF VITAL POINTS

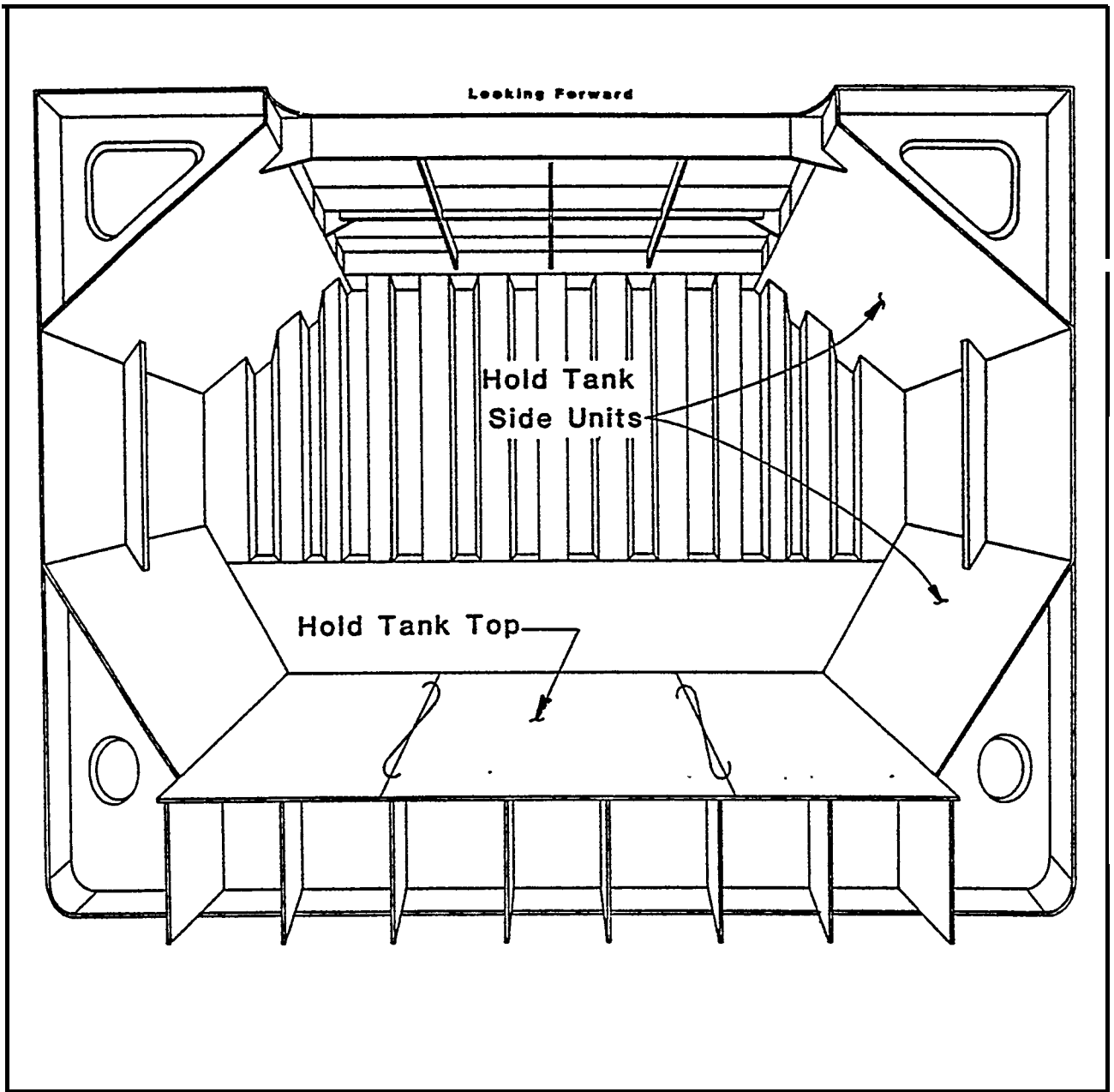
Accuracy of the total ship lines and of the blocks at erection is the ultimate objective of the Accuracy Control system. The major sections of the ship designated for rigid control of accuracy are: the hold sections; the curved sections; and the stern.

3.2.1 Hold Sections

These sections represent the majority of units in the ship and are considered most critical from the standpoint of maintaining the ship's lines and accuracy. Critical points of measurement are concerned with both the skin curvature of the hold bottom units and with the internal hold structure.

Vital points of hold sections are generally separated into two parts: the Tank Top and the Top Side Tank. This separation allows a workable division of erection units and also provides a logical erection sequence to be developed for all of the mid-ship sections.

Figure 3-2 shows the configuration of these two parts of the hold sections.



HOLD SECTION

FIGURE 3-2

The Tank Top is the basic unit of the hold section. The erection of the assemblies which make up the Tank Top is most critical to ship alignment and, as a consequence, these assemblies are carefully checked

for accuracy both during assembly and during erection. At erection, three different accuracy checks are made on each assembly unit. These accuracy checks are designated by Accuracy Control engineers in Erection Plans as discussed in the prior section. The vital points designated for checking are: Center Line Check; Relativity Check and Level Check.

The Center Line Check concerns the validation of the ship's center line as each unit is landed in a hold section. This check is accomplished two separate times, once before fitting and once after welding. Checking is performed by transit and the usual tolerance allowance is 1/8 inch.

The Relativity Check is performed on three different types of units: the center double bottom units, the center side double bottom units and the bilge units. Every unit is checked prior to fitting and at least once after welding. Checking is performed by transit and the usual tolerance is 1/8 inch, however, if the deviation of a unit is larger than 1/8 inch but less than 1/4 inch, the deviation is acceptable as long as the overall hold relativity is maintained within tolerance.

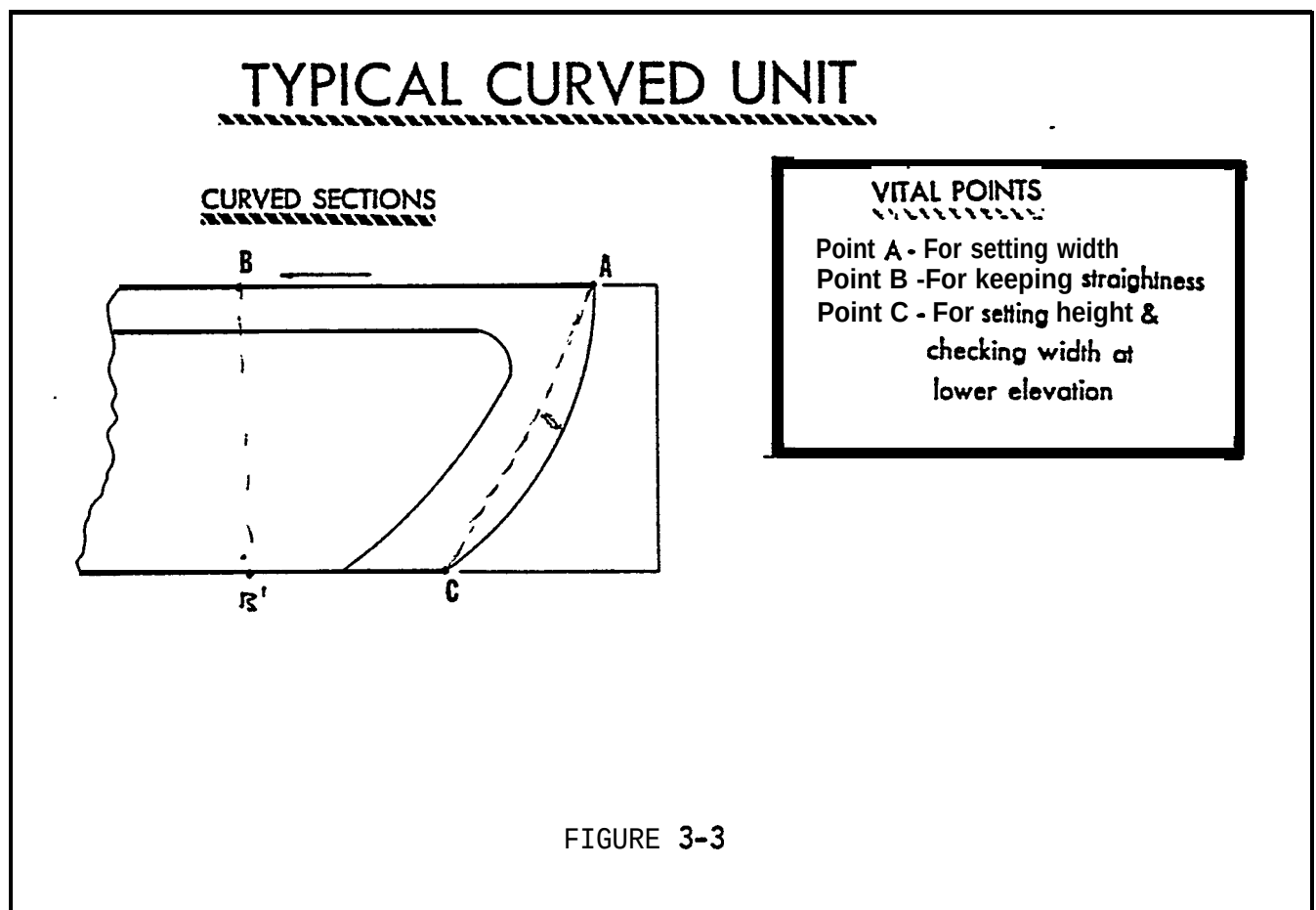
Level checks are performed on every erected Tank Top unit before fitting and after welding. Vital points are measured at the front frame at the top of the unit as installed. After welding, the bottom of each unit is checked for alignment with adjacent units.

Similar check points are defined and designated for the Top Side Units. Critical points of accuracy control on these units are: the straightness of the Base Line; the width of the ship at the main deck;

the height of the **ship** at the main **deck**; and the level of the main **deck**.

3.2.2 Curved Sections

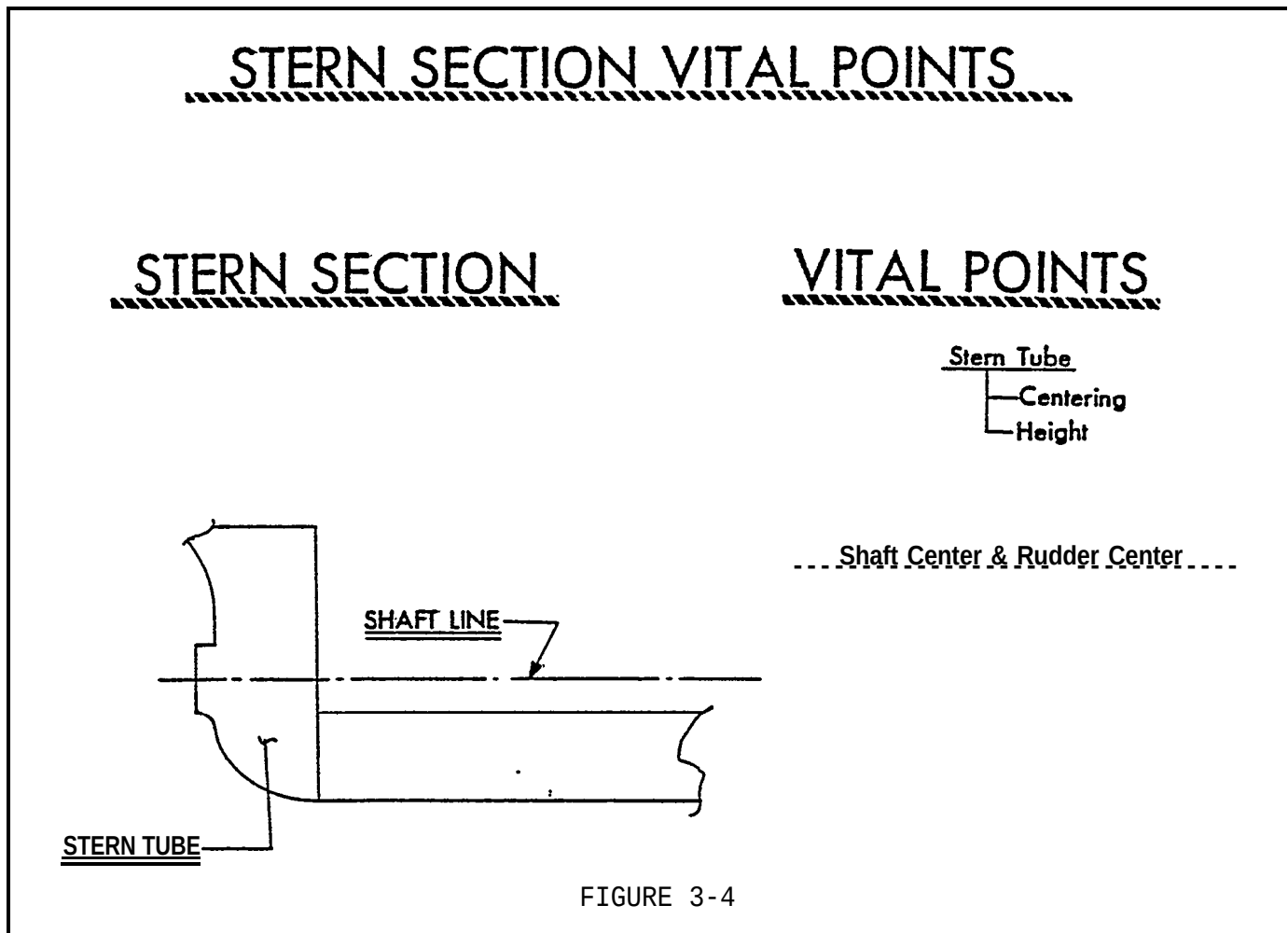
Curved sections are **also** critical to the overall alignment of the **ship**. In order to maintain accuracy of these **sections**, Accuracy Control Engineers establish those **points which are most** amenable to measurement and which will assure accuracy of alignment both vertically and horizontally. Since these units have different widths at the top and the bottom of the unit and since mating units must accurately match with the top and bottom **curve**, it is imperative that these **curved** sections be carefully aligned upon **erection**. **Figure 3-3** shows a typical curved unit and the vital points usually established for erection of such a unit.



As shown in the figure, the width of the upper part of the unit and the width of the bottom part of the unit are set individually as are the height and the straightness of the unit. Accuracy Control Engineers not only prepare the information on these vital dimensions and points of measurement but also accomplish the actual measurement as these units are erected.

3.2.3 Stern Section

Accuracy control of the assembly units comprising the stern is especially necessary because of the requirement to preserve the alignment of the stern tube. The vital dimensions and points of accuracy are carefully defined by Accuracy Control Engineers to: maintain the



accuracy of the center of the stern tube in both height and lateral **direction**; maintain the relationship between the center of the stern tube and the shaft **line**; and, maintain **the** relationship between the shaft center and the rudder **center**. These relationships are extremely difficult to maintain and require careful planning and measurement during **erection**.

3.3 ASSEMBLY STAGE PLANNING OF VITAL POINTS

Accuracy planning of the vital dimensions and points of measurement is particularly important in the assembly stage of ship construction. Accuracy control of the unit assemblies encompasses complete assessment of **every** construction feature of typical or common assemblies found mainly in **the mid-body of** the ship and even more **detailed** checks of unique units peculiar to the **forepart** and the **stern**. The determination of these vital points on each unit comprises a large part of the Accuracy Control effort during the planning **phase**. "-

Vital point planning for unit assemblies is divided between the two basic types of **assemblies**: flat unit assemblies and curved unit **assemblies**.

3.3.1 Flat Unit Assemblies

Flat Unit Assemblies are generally mid-ship units comprising the cargo hold and double bottom sections of the **ship**. Although the mid-ship section accounts for the greatest number of units there are only several different types of units in this **section**. A majority of these units are flat panel assemblies which are processed in an identical manner through the **fabrication**, sub-assembly and assembly **stages**. Accuracy Control vital dimensions and points of measurement therefore

are fairly standard and are followed routinely by the production workers.

Vital dimensions and accuracy points for **these** units are planned from the time plates are combined into **panels**. Vital dimensions are prescribed for the panel **to confirm length**, width and squareness (by specifying diagonal **dimensions**). When **stiffeners**, girders or webs are attached to the **panel**, the vital points specified for accuracy measurement **involve**: edge **alignment**, girder **spacing**, straightness of each **girder**, and **the** level of the **assembly**. Figure 3-5 depicts the vital points specified for one type of flat panel unit.

3.3.2 Curved Unit Assemblies

Curved Unit Assemblies are of two **types**: curved shell on a flat panel base and a curved assembly on a curved shell **base**. In the case of the unit on a **flat** panel **base**, vital points are assigned **to**: edge alignment at each **frame**; **shift** at each **longitudinal**; inclination at each **frame**; and the level of the panel **base**. Other vital points are designated according to the type and shape of the unit being **analyzed**.

The curved assembly on a curved **shell** base is more difficult not only in the calculation and assignment of accuracy control points but **also** in actual measurement 'in **production**.

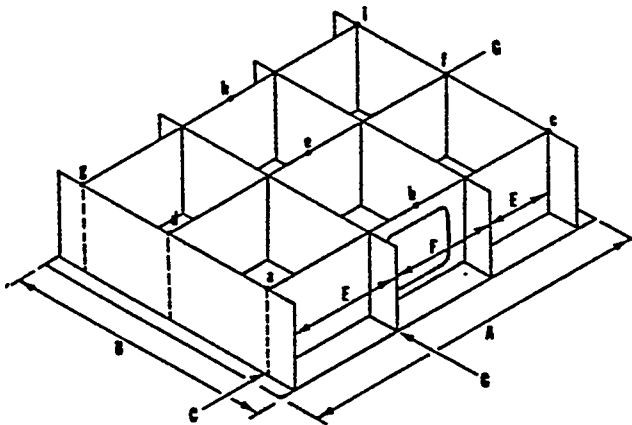
IHI utilizes pin jigs for support of a curved **shell** base which requires some additional accuracy control **considerations**. Vital points in this case are assigned **to**: exact positioning of the curved shell plates on the pin **jig**; assembly finish marking on the shell plate (**for** alignment with adjacent **units**); setting the exact fitting angle of all internal structure members on the shell **plate**; checking the relative

Vital Dimensions & Points of Accuracy

Assembly Stage

FLAT UNIT ASSEMBLY

Before being combined with bottom plate



VITAL POINTS

Edge Alignment - Every girder
both sides

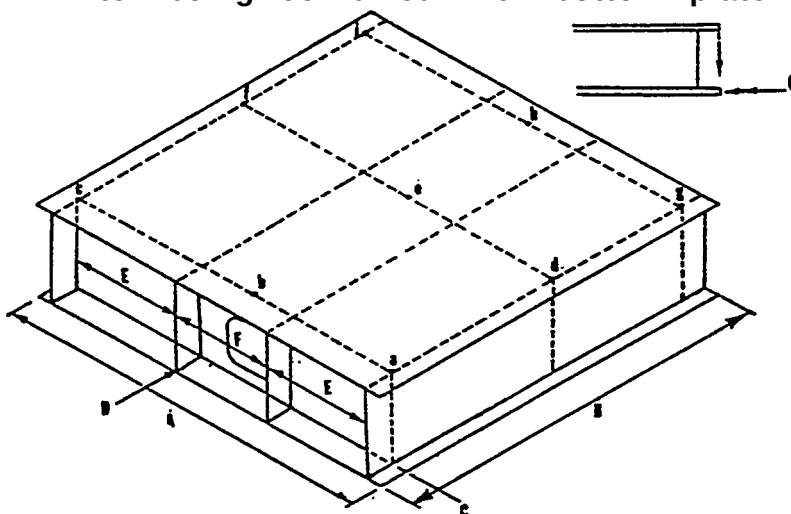
Girder Spacing - Every frame

Straightness - Each girder

Level - 9 points

FLAT UNIT ASSEMBLY

After being combined with bottom plate



VITAL POINTS

Edge alignment -
every girder
both side-s

Girder spacing -
every frame

Relativity -
2 points each
edge

Level -
9. points

FIGURE 3-5

dimension between the **shell** plate edge and the internal **structures**; and prevention of deformation which may be caused by **welding**. Maintenance of accurate **shape** of the curved shell unit is the overriding concern during this type of **assembly**. Figure 3-6 shows these two types of assemblies and the respective vital **points**.

Throughout the identification and definition of the vital dimensions and points of measurement for **assemblies**, Accuracy Control Engineers are concerned with two primary **considerations**: 1) identification of the points which **will** assure the greatest accuracy in the erected ship **configuration**; and 2) identification of those points which will be most difficult to maintain during the assembly **process**. These considerations are the basis of these Accuracy Control **decisions**.

3.4 FABRICATION STAGE PLANNING OF VITAL POINTS

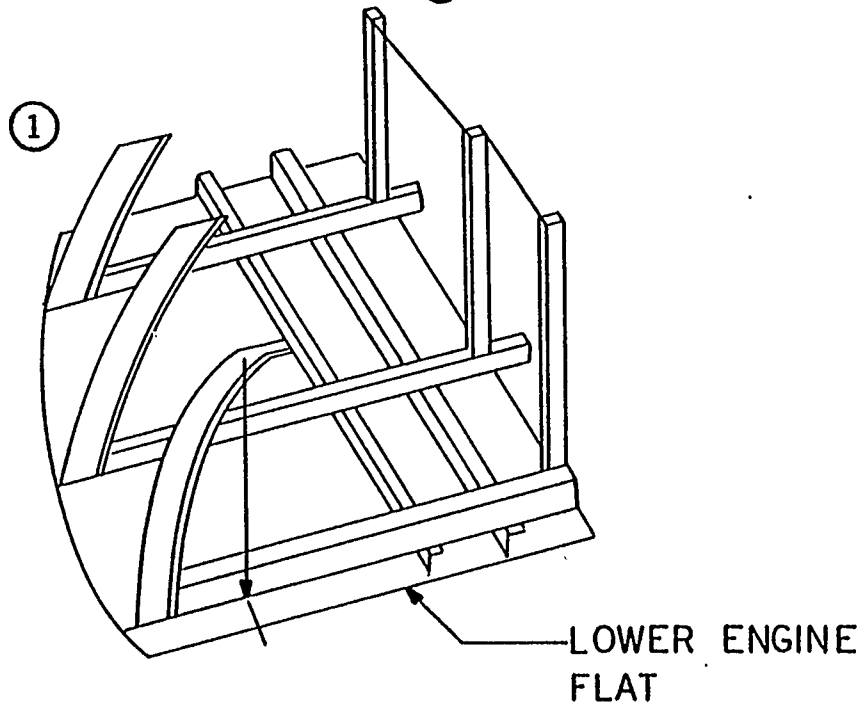
Selection and designation of vital dimensions and measurement points during the fabrication and sub-assembly stage requires the **examination** of the individual piece parts to be fabricated for each **assembly**. Maintenance of high accuracy during the fabrication stage naturally **yields** easier and more accurate assembly work and ultimately erection **work**.

In assignment of vital dimensions and accuracy control points the fabrication process is viewed from all aspects of **marking, cutting, bending** and **sub-assembly**. Working backward from the accuracy control planning accomplished on the assembly **units**, discrete sub-assemblies and piece parts are identified which **must** be controlled in order to maintain the accuracy required during **assembly**. The **sub-assemblies** and piece parts thus identified are then analyzed as to the fabrication

CURVED UNIT ASSEMBLIES

CURVED UNIT

ON FLAT PANEL - ①
ON CURVED PLATE - ②



VITAL POINTS

MAX. CURVATURE DEPTHS

EDGE ALIGNMENT

AT EACH FRAME

SHIFT

AT EACH LONGITUDINAL

INCLINATION

AT EACH FRAME

LEVEL

TRANSIT

TWIST DEFORMATION

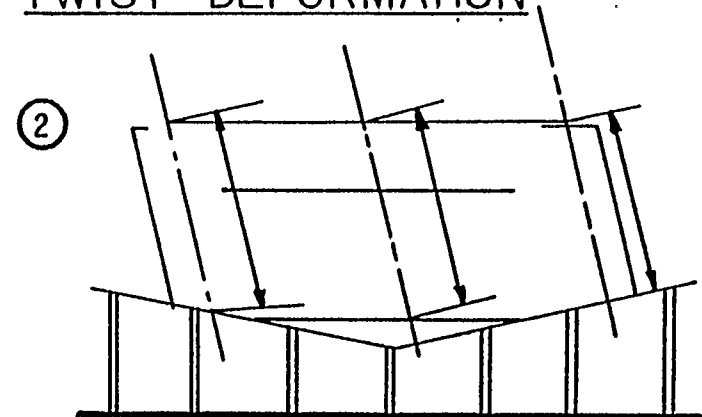


FIGURE 3-6

processes that must be used to manufacture them and vital dimensions and accuracy points specified for each part in each process (i.e. plate marking, cutting dimensions and requirements for dimensional checks, bending dimensions and checks, etc.) Typical vital points specified for fabricated pieces and sub-assemblies are: length; width; height; squareness; level; edge condition; deformation caused by welding; twist; relativity of stiffeners, girders, webs; straightness of stiffeners, girders, webs; etc.

The identification and designation of these vital points and dimensions is disseminated through working drawings, assembly specification plans, working instruction plans and through the development of Accuracy Control Check Sheets which are used throughout the fabrication, sub-assembly, assembly and erection process by workers, Accuracy Control personnel and Quality Control personnel.

SECTION 4

PLANNING FOR ADDITIONAL MATERIAL

4.1 GENERAL

Accuracy Control is effected in several ways in the IHI ship construction process. All of the preliminary and detailed process planning certainly contributes to better, more accurate fabrication, sub-assembly, assembly and erection work. The identification and designation of vital dimensions on working drawings and of vital points of accuracy measurement in Accuracy Control Check Sheets provides workers, Assistant Foremen, Foremen, Accuracy Control personnel and Quality Control personnel with definitive guidelines for exact workmanship and product standards. However, the maintenance of precise accuracy at each step of each production stage is virtually impossible due to the large number of uncontrollable factors present at any given time in the manufacture of ship piece parts, components and assemblies.

Because of this inability to absolutely control accuracy by any of the above means IHI has developed a systematized Accuracy Control method for providing additional material in some parts and components of the ship. This added material is specified for each fabricated piece at each production stage. The added material is "cut away" only when each piece is mounted or affixed to the next larger sub-assembly or assembly. For example, the added material on individual pieces cut from plates is removed when these pieces are combined into a flat panel sub-assembly. The panels of the sub-assembly will also have added material which will be removed either when that sub-assembly

becomes part of an assembly or during erection of the assembly if those panels form part of the exterior of the assembly. Hence, neat cutting occurs at different points in fabrication, assembly and erection.

The objective of this accuracy control planning is to compensate for any inaccuracies in layout, burning or fitting and any shrinkage or deformation caused by welding. This Accuracy Control planning is therefore a critical and highly involved part of the total Accuracy Control concept.

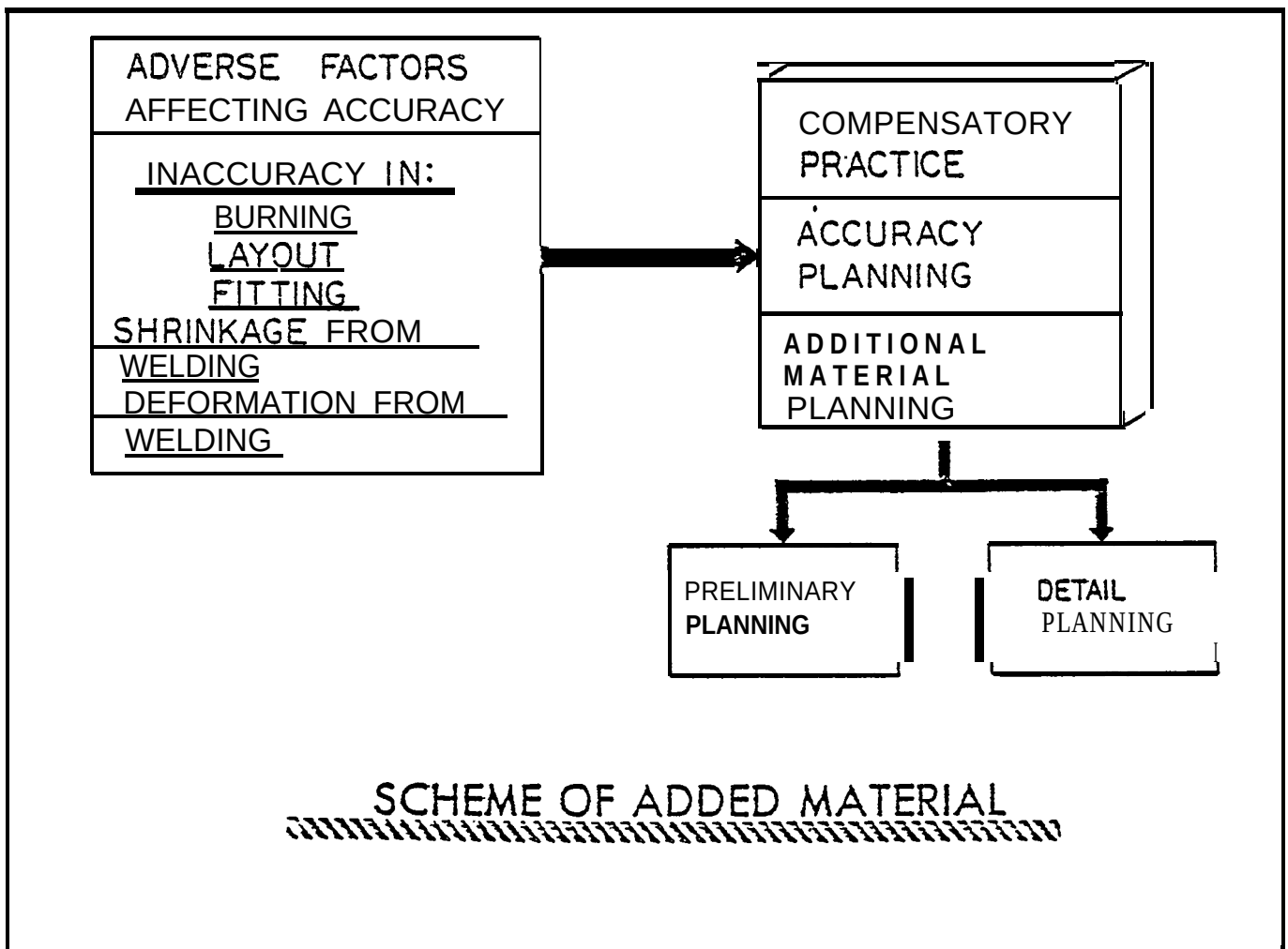


FIGURE 4-1

Actual additional material planning involves two distinct phases of **activity**: preliminary planning and detail **planning**. Preliminary planning concerns the establishment of the added material scheme for the entire ship whereas the detail planning is concerned with the **requirements** for added material for detail parts such as internal **structures** and **joints**.

4.2 PRELIMINARY PLANNING

In this phase of added material **planning**, Accuracy Control Engineers perform a detailed analysis of key ship construction **plans**, unit assembly methods and the erection **plan**. This analysis **involves** a review and assessment of the **Hull Blocking Plan**, mid-ship section and shell expansion **drawings**.

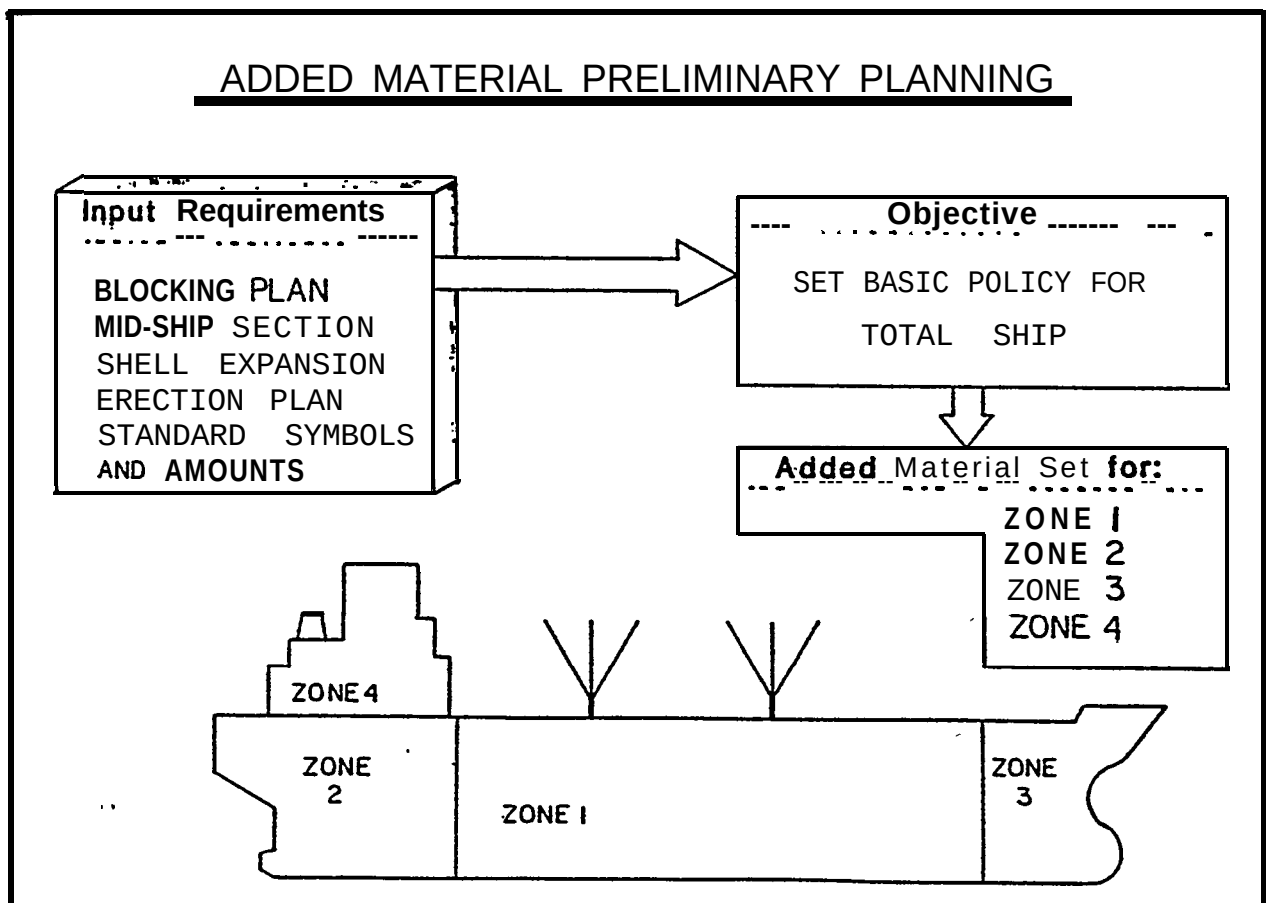


FIGURE 4-2

On the basis of this analysis the added material scheme is first established for the mid-ship sections. The primary considerations used for making the added material decisions are: 1) which dimensions are most important from the standpoint of maintaining the overall accuracy of the ship; 2) which dimensions are most difficult for maintaining accuracy; 3) which stage is most suitable for cutting erection joints neat; 4) how much added material is required for each erection joint.

The process of determining the added material for the mid-ship sections essentially follows these steps:

- 1) determine the erection order of each assembly unit from bottom to top, and from center units to the outside units;
- 2) examine each unit to decide which surfaces are most important to preserve the dimensions specified on the design drawings (such as depth, width, length of ship, etc.);
- 3) designate each of the critical surfaces (determined in 2 above) as either "important part" or "difficult part", by affixing the proper symbols to the unit working drawing;
- 4) decide the amount of added material required for each critical surface and the point at which neat cutting of the surface should occur;
- 5) designate the location and amount of added material and the stage of neat cutting by affixing the proper symbols to the unit working drawing and the shell expansion drawing.

This process is used to establish the added material for the fore part and stern of the ship after the mid-ship sections have been completed.

Subsequent to this Accuracy Control planning for added material, applicable dimensions and added material information are entered on the working drawings by the shipyard Design Department Engineers and released to the yard workshops.

4.3 DETAIL PLANNING

Detail added material planning is concerned with keeping the accuracy of detail parts during fabrication, sub-assembly and assembly. This effort is based on the preliminary planning and is accomplished by the design engineers in the Design Department.

As in the preliminary planning each of the component parts of a sub-assembly or assembly is examined together with the necessary production processes which must be applied in their manufacture. Decisions are made concerning the most important dimensions, the most appropriate stage (or sub-stage) for neat cutting, and how much added material is required for each surface of a fabricated item. Neat cutting can be designated at the cutting (burning) sub-stage, after bending or flaming, or after joining either at the sub-assembly or assembly stage.

The process used by design engineers in determining added material requirements is similar to that used by the Accuracy Control Engineers in the preliminary planning. Block Assembly Plans are used to determine the breakdown of pieces and sub-assemblies and the fabrication processes through which each piece must flow. Each piece is examined to decide which surfaces are critical to the accuracy of the subsequent sub-assembly or assembly, which surfaces will be most difficult in which to preserve accuracy, and which dimensions are most important

ADDED MATERIAL DETAIL PLANNING

OBJECTIVE

KEEP ACCURACY OF DETAIL PARTS TO OBTAIN ACCURACY IN UNIT ASSEMBLIES.

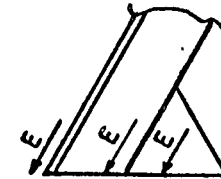
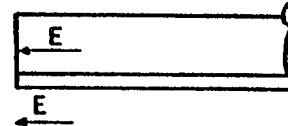
PRELIMINARY ADD.
MATERIAL PLAN

WORKING
DRAWINGS

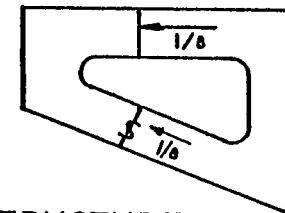
DETAIL ADD.
MATERIAL
PLANNING

DETAIL PLANNING STANDARDS

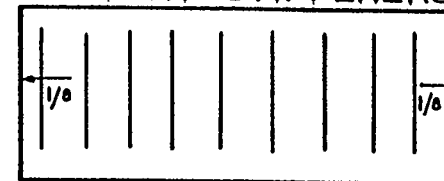
TYPE 1-UNIT JOINT EDGE



TYPE 2-INTERNAL JOINT



TYPE 3 - INTERNAL STRUCTURE WITH STIFFENERS



TYPE 4 - INTERNAL MEMBER

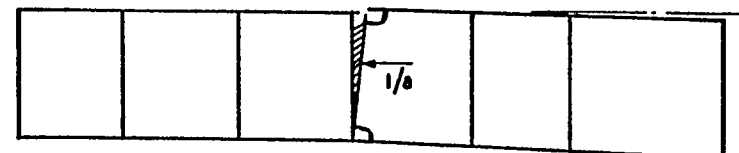


FIGURE 4-3

to ensure proper alignment and accuracy in the finished assembly. Based on these determinations the locations and amounts of added material are decided and designated on the working drawings. Figure 4-3 shows the type of planning for additional material on structural parts.

4.4 ADDED MATERIAL SYMBOLS

Additional material is indicated on working drawings by a standard set of symbols used to indicate the location of added material, the amount, and when the material is to be cut neat. These symbols and examples of their application are presented in Figures 4-4 through 4-6.

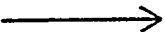
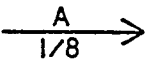
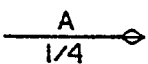
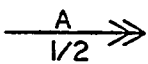
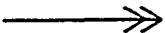
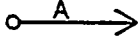
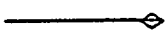
<u>ADDED MATERIAL SYMBOLS</u>		
<u>Standard Symbols</u>		<u>Amounts</u>
<u>SYMBOLS</u>	<u>MEANING</u>	
	— CUT NEAT AT FAB.	 — 1/8" ADDED MATERIAL CUT NEAT AFTER PLATE JOINING.
	— CUT NEAT AT ASSY.	 — 1/4" ADDED MATERIAL CUT NEAT AFTER FINAL ASSEMBLY.
	— CUT NEAT AT ERECTION	 — 1/2" ADDED MATERIAL CUT NEAT DURING FINAL ASSEMBLY
	— CUT NEAT AS ADJUST-ING.	 — ADDED MATERIAL MORE THAN 1" AFTER PLATE JOINING.
	— CUT NEAT DEPENDING ON DIMENSIONAL CHECK WITH TRANSIT	
	— CUT NEAT AFTER BENDING	
	— CUT NEAT DURING FINAL ASSEMBLY	
	— CUT NEAT AFTER FINAL ASSEMBLY BY DIMENSIONAL CHECK	

FIGURE 4-4

SCHEME of ADDED MATERIAL-PRELIMINARY PLANNING

Additional Material Planning Shell Expansion

Aft Section

NOTES:

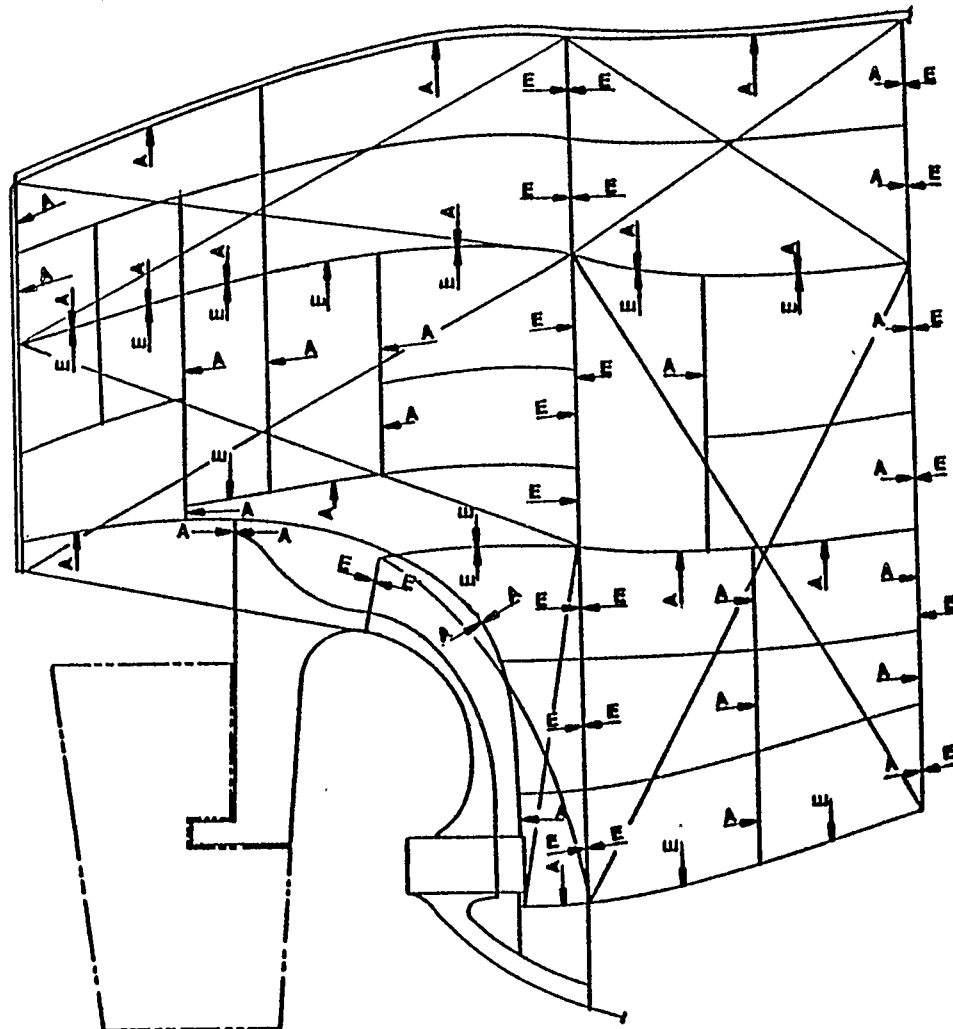


Apply curved unit
lig system.

A →: Cut neat at asy.

E →: Cut neat at erection.

No Mark: Cut neat at fabrication.



Scheme of Added Material — Detail Planning

Added Material Calculation

MAIN PLATE TRANSVERSE SHRINKING FROM CONTINUOUS FILLET WELDING ON LONGITUDINAL STIFFENER

$$S = \frac{L}{25 \times T} \times N$$

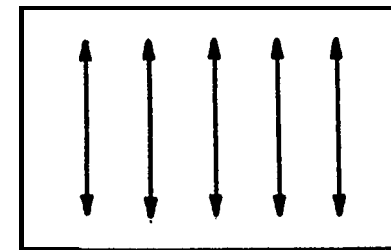
WHERE:

S = TRANSVERSE SHRINKAGE

T = THICKNESS OF PLATE

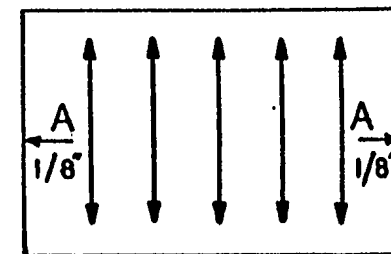
L = LEG LENGTH (CONT. WELDING)

N = NUMBER OF STIFFENERS



$$\begin{aligned} T &= 1/2'' \\ L &= 1/2'' \\ N &= 5 \end{aligned}$$

$$S = \frac{1/2''}{25 \times 1/2} \times 5 = 1/5'' = 1/4''$$



ADDED MATERIAL 1/8" PER SIDE .

FIGURE 4-6

SECTION 5
ACCURACY CONTROL BASE LINES

5.1 GENERAL

Another aspect of Accuracy Control planning is that concerned with the establishment of base lines for fabricated pieces and assemblies. These base lines are used at each stage of production to obtain accuracy in cutting, shaping and preserving the proper relationship between component parts on the sub-assembly, assembly and erection units.

Accuracy Control Engineers perform the basic (preliminary) planning for these base lines in conjunction with mold loft personnel. Implementation of base line information is accomplished by the mold loft for fabricated pieces"and by Accuracy Control during the assembly and erection stages. The basic planning consists of the identification of base lines at each production stage and (in the case of fabrication) the provision of guidelines to the mold loft for preparation of N/C tapes, instructions for manual marking and for preparation of base line marking tapes (i.e. metal strips used by workers to determine base lines on fabricated parts, sub-assemblies and assemblies.)

Essentially there are three types of base lines: check line for cutting; check line for shaping; and base-line for relationship between materials.

5.2 CHECK LINE FOR CUTTING

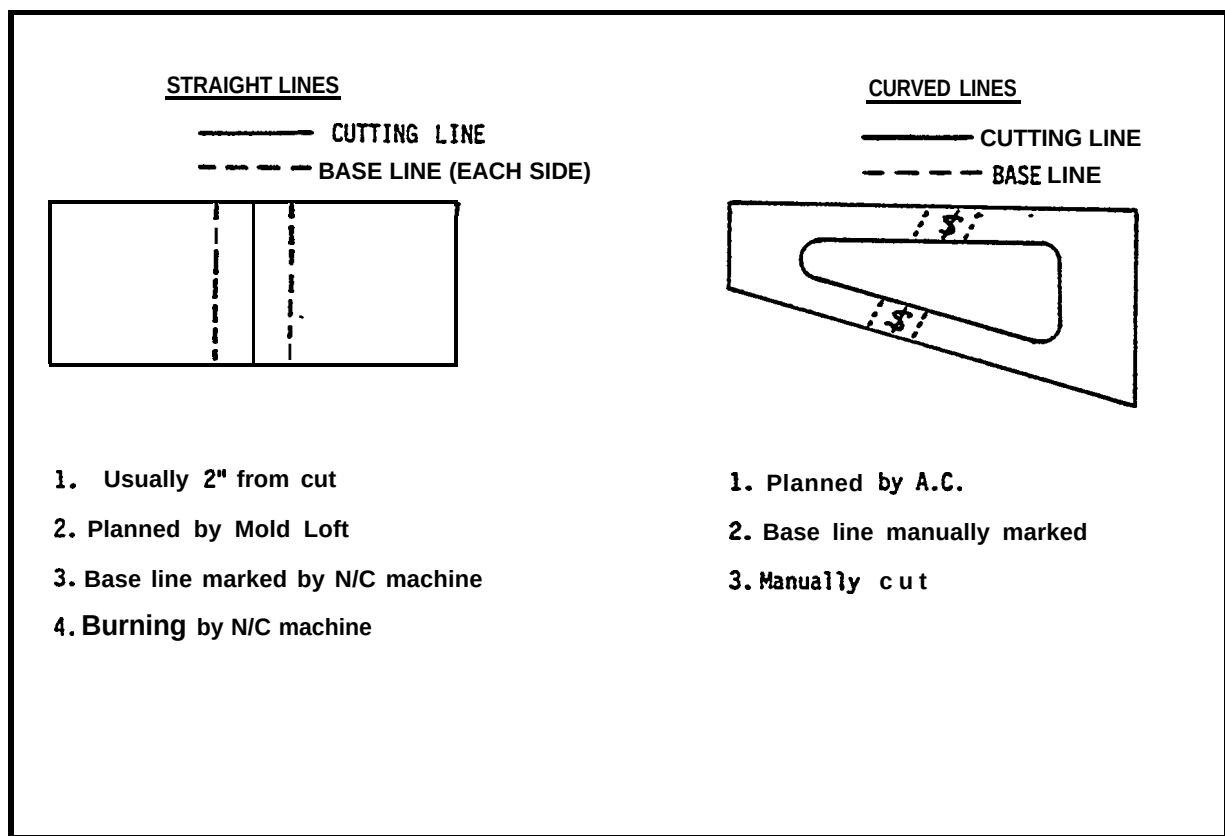
This base line is applied to flat plates which are to be cut in a straight or curved line either by an N/C burning machine or manually.

Usually the check (base) line is planned at a constant dimension

of two inches inside the cut line. In the case of a straight line cut, the checking line is planned by the mold loft for materials having a straight joint such as internal structures which will be joined to flat panels.

Check lines for materials such as engine flats or curved web frames, which must be cut manually, are similarly placed inside the cutting line usually by hand using some sort of jig. In this case the check line serves as a guide during the manual cutting and also as a constant reference in determining the accuracy of the cut line.

Figure 5-1 shows the application of these check lines.



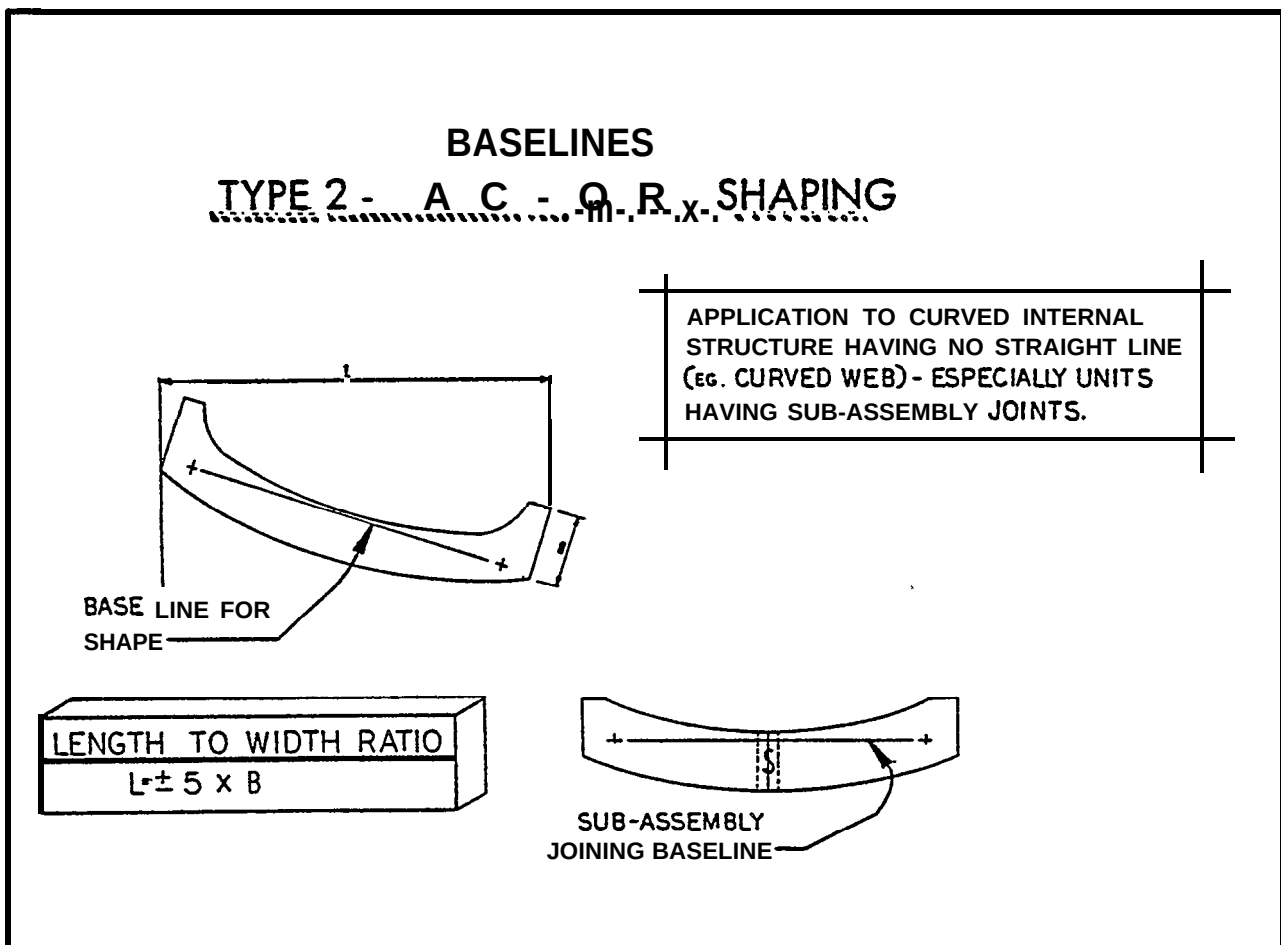
BASE LINES FOR CUTTING

FIGURE 5-1

5.3 CHECK LINE FOR SHAPING

In order to maintain the shape of curved units having no straight edge or line, a base line is established by the Accuracy Control group to assure that the shape conforms to drawing requirements and that distortion does not occur after welding.

This base line is marked either by the N/C machine or manually using an appropriate jig. The line usually extends the full length of the curved component and as a "rule of thumb" about five times the width of the component.



BASE LINES FOR SHAPING

FIGURE 5-2

Having established the base line as a straight line reference, measurements can be taken from the base line to as many sections of the shape as warranted and comparisons made between shape condition before and after welding and with required dimensions stipulated on the working drawing. Figure 5-2 shows the application of this type of base line to shaped components and sub-assemblies.

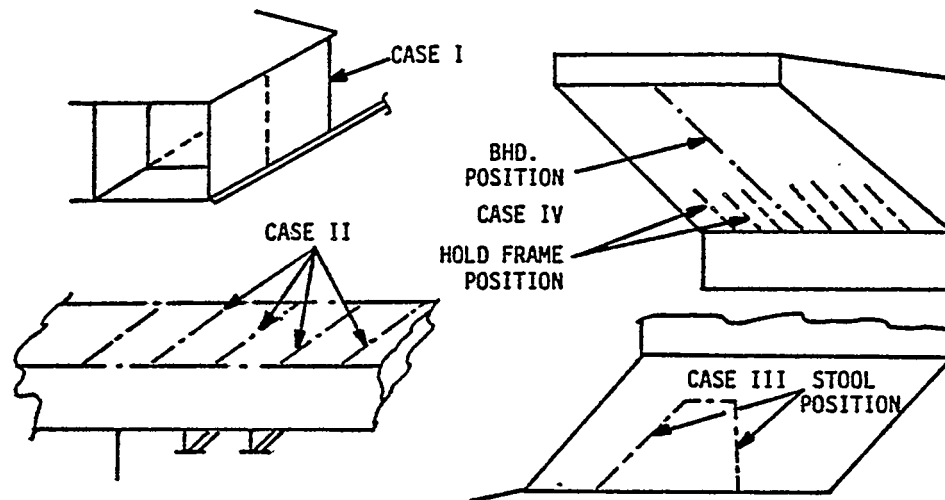
5.4 BASELINES FOR MAINTAINING ACCURACY IN THE RELATIONSHIP OF MATERIALS

Base lines used for the proper alignment of materials when joined to adjacent components or assemblies are most important in preserving the overall accuracy of the erected ship. These base lines are applied at each production stage to assure that the sub-assemblies, assemblies and erected units are in proper alignment with each other.

During the fabrication stage these base lines are used to set stiffeners, face plates and brackets on transverse frames or girders. These base lines are generally set by the mold loft.

At the assembly stage two different base lines are used to maintain material relationships. One type of base line is called "back side marking" where the base line is actually applied to the reverse side of the components to be joined. The base line is applied in this manner because of some type of interference such as a girder or bulkhead separating the two units or components which precludes using a direct sight line on the front side. Figure 5-3 shows this type of base line marking.

The other type of base line is primarily used for joining curved sections of an assembly. This base line is applied to flat plate prior



CASE I : Back side marking on girders between double bottom units.

CASE 11: Back side marking on t-top between stools and double bottom.

CASE 111: Back side marking on slant plate.

CASE IV: Back side marking on top side tank bottom plate.

ASSEMBLY BASE LINES

FIGURE 5-3

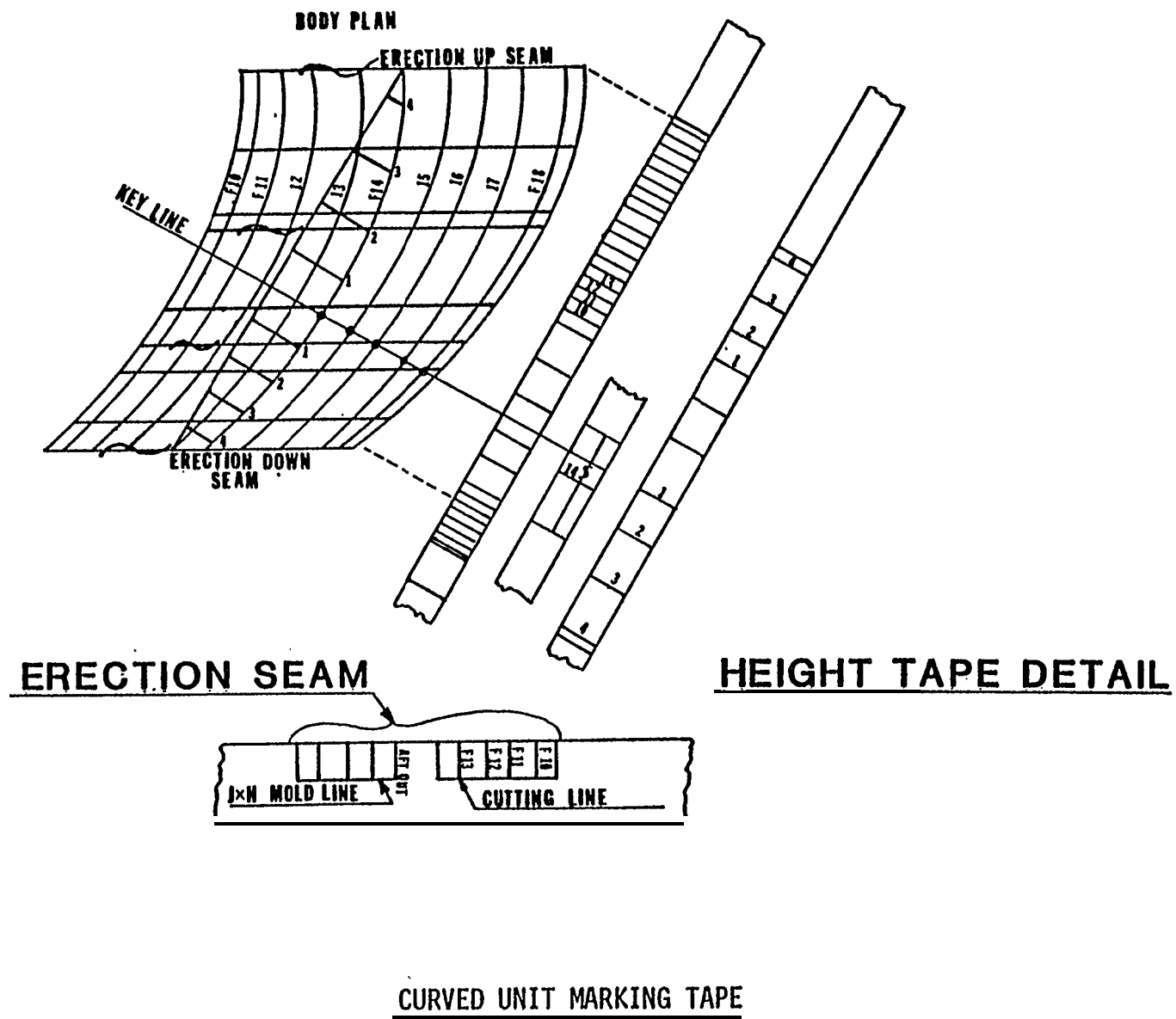
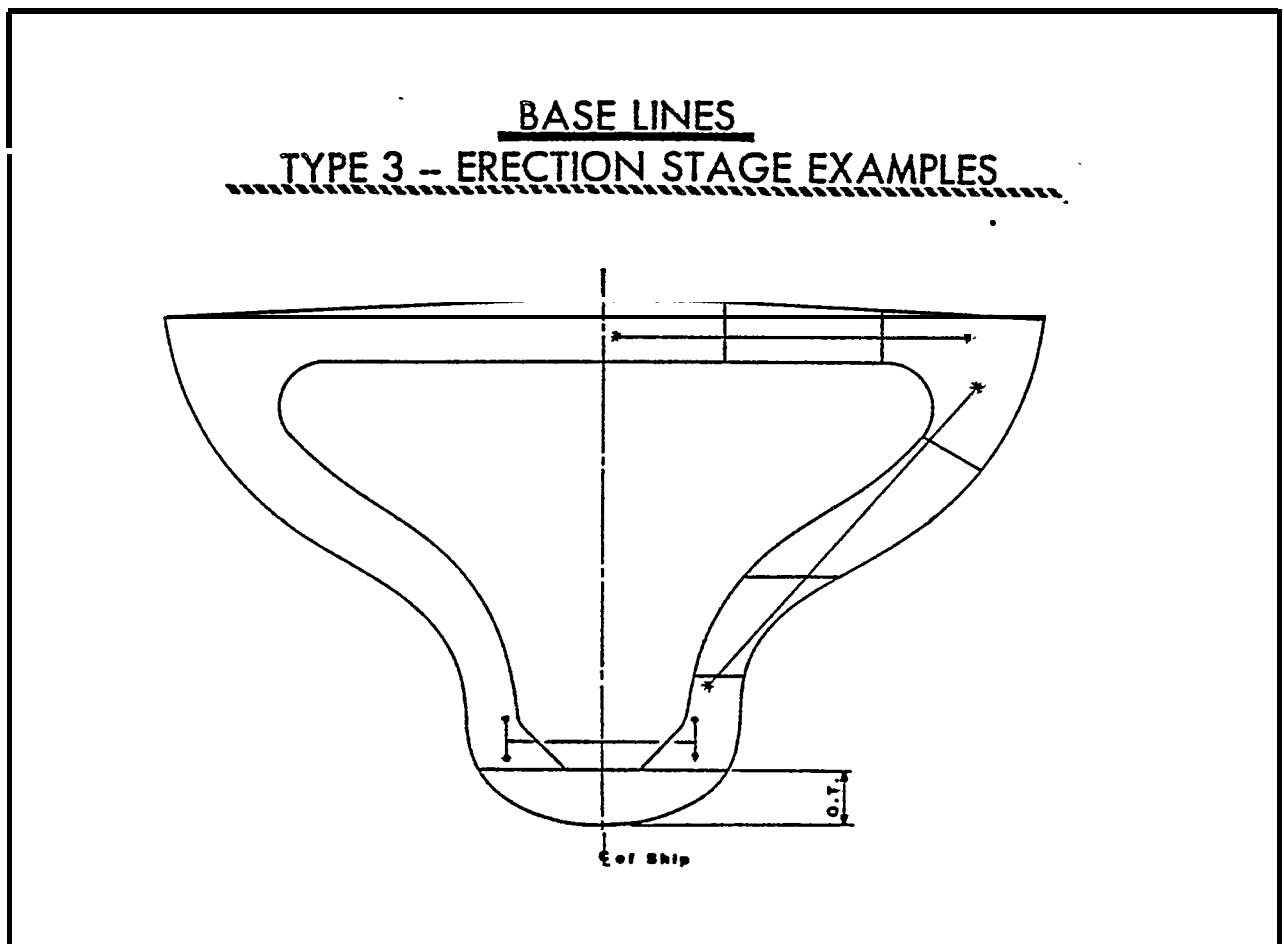


FIGURE 5-4

curved **plate assemblies**. These marking tapes are thin metal strips precisely measured to show the reference points applicable to a specific **plate**. Using the marking tapes each curved assembly **plate** is checked for proper configuration and proper position of the base line (**after bending**). This **checking** of each bent **plate** assures successful alignment of the **plates** on the pin jig and with adjacent mating **plates**. Figure 5-4 illustrates a **typical** Curved Unit **Assembly Marking Tape**.

Another important base **line** applied during the assembly process is the base line for **alignment** of completed curved **units**. For **example**,



ASSEMBLY BASE LINE MARKING
(CURVED UNITS)

FIGURE 5-5

where many units are mounted one on top of another in a continuous curved section of the ship (e.g. bow sections), a base line is established that runs through the center of the units in an oblique direction. Matching these base lines allows proper alignment of each unit as it is mounted. Figure 5-5 shows this type of base line.

During the erection stage two types of base lines are used. The first base line is physically marked on the shipways to show the absolute ship center line and the aft butt position of the first unit to be landed on the ways. Additionally, specific unit base lines are marked for many of the bottom assemblies on the ways. For example, the forward end frame position of each unit for the ship's fore part and stern are marked and the aft end frame position of each unit for the mid-ship sections. Watertight bulkhead positions, the aft perpendicular and the forward perpendicular points are also marked.

Accuracy Control Engineers are responsible for the planning and actual marking of these base lines on the ways. The plan for the layout of these base lines is usually contained in the cribbing plan.

The second type of base line used for erection is marked on each unit prior to movement to the erection area. Both the planning of these lines and the actual marking is accomplished by Accuracy Control Engineers. These base lines are used to set completed assembly units in position on lower units in the erection sequence and for aligning each unit fore and aft with adjacent units. These are called base lines for shipwrighting.

SECTION 6

TOLERANCE STANDARDS

In all IHI shipyards the use of tolerance standards is an integral part of the design and production process. Tolerance standards have evolved from actual production practices over many years and many a series-run of ships. For many ship types standard tolerances are firmly established and require little, if any, modification. In these cases Accuracy Control Engineers simply review ship specifications for any requirements that would cause a change to those already in practice. In the case of a new ship type standard tolerances are reviewed and changes effected where necessary to comply with specification requirements or with differing technical requirements for that ship. Generally no major revision of tolerance standards is required even on new ship types.

Tolerances may be modified as a result of the Accuracy Control planning for vital dimensions and points of accuracy on individual components or assemblies. The data collected by Accuracy Control groups at the time of measurement of sub-assemblies or assemblies may indicate a change to a certain tolerance at some particular stage of processing. The data analyzed may, for example, show a trend toward an out-of-tolerance condition through the accumulation of marginal tolerances in several pieces combined into one sub-assembly. In this case certain tolerances would be adjusted to assure that the accuracy of the sub-assembly was preserved. This type of tolerance control is called "Special Control", and is primarily oriented toward improvement

of tolerance standards for a particular ship type.

A second type of control is called "Regular Control" and is concerned with the routine tolerance accuracy of the fabricated pieces of any ship and with the accuracy maintenance of the machines which process those pieces.

Accuracy Control Engineers are responsible for field checks of both the fabricated pieces and of the related machines such as the N/C burning machine, the flame planer and all welding machines. Results of these field checks are analyzed and plotted on time-based control charts to detect any increase in out-of-tolerance performance.

Figures 6-1 and 6-2 present examples of the standard tolerances established for each type of control.

In IHI a well developed set of standards provide detailed information to designers, planners, production workers and Quality Control Inspectors throughout the ship construction process. These standards have been included in the Livingston Technology Transfer Program Final Report on Quality Assurance.

SHOP	ITEM	TOLERANCE	FREQUENCY OF MEASURING	REMARKS
<u>ERECTION</u> Bottom Shell	*Positioning (Length wise) Measure on the check points on berth	$e = \pm 1/8"$	Starting unit only	
	*Positioning: (Height) Measure at the most forward frame (2 points)	$e = \pm 1/4"$	All Units	By Gauge
	*Level: (Between left side and right side) Measure on the points at forward edge	$e = \pm 1/4"$	All Units	Pay attention to twist
	*Positioning: (Between left side and right side) Measure at the forward butt	$e = \pm 1/8"$	All Units	Plum down to the base line on berth
	*Connecting part between units: Check the bevels at seams and butts	$e = \pm 1/8"$	All Units	
	*Discrepancy of ship's center	$e = \pm 1/8"$	All Units	Measuring by transit
FIGURE 6-2 TOLERANCE STANDARDS SPECIAL CONTROL (EXAMPLES)				

SECTION 7

CONCLUSION

The planning functions of Accuracy Control are an integral part of the **total** production planning **process**. The participation of Accuracy Control Engineers with designers and production planners in the design **development**, the ship breakdown, and in the determination of production **processes**, methods and techniques is a sophisticated and highly developed aspect of the **IHI** production planning and control **system**. Although the activities of Accuracy Control are separately identifiable, in reality the production planning system functions as a group effort with contributions from many different groups to a cohesive and comprehensive manufacturing **plan**.

Accuracy Control **planning** can be seen as a discrete sub-system within the overall planning **system**. Accuracy Control planning-consists of two basic **elements**: participation in production **planning**; and the development of specific inputs to the detailed Assembly Specification **Plans**, the working drawings and the **Working** Instruction Plans for each assembly **unit**. This planning forms the basis not only for the control of accuracy but also for the **utilization of facilities, manpower and equipment** throughout the **production process**. In effect the **planning** accomplished by Accuracy Control Engineers in the preliminary planning stages establishes the operations and practices to be observed during the entire ship construction **program**.

Although the emphasis of the Accuracy Control Engineers is on maintaining precision at each stage of **production**, the requirements

stipulated in detailed plans for achieving that precision necessitate particular **processes**, methods and **techniques**. These requirements therefore regulate and **control** the production **system**, the quality of the end **product**, and ultimately the productivity of the production **process**.

The **planning**, by **itself**, is of course no guarantee of proper **execution**, **however**, the Accuracy Control system does not end with **planning**. The field activities of Accuracy Control ensure that the planning is **executed** properly and through the Accuracy Control data **collection**, **analysis** and feedback **activities**, that the production system is **continually improved**.

The concept and **system** of Accuracy Control within IHI thus operates through the entire design/production process to plan and specify accuracy and production **requirements**, to monitor and measure the product and the production **system**, and to perpetually refine and improve the **products**, the production system and the **productivity** of the **IHI yards**.

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