6.0 SUGGESTIONS

6.1 Design

The hull-block construction method developed naturally following the introduction of welding many years ago. Some shipbuilders changed their organization of structural drawings to suit. Appropriate drawing titles evolved such as: *block erection plan*, *block assembly plan*, *sub-block assembly plan* and *part-cutting plan*. These are more than traditional detail-design drawings because they associate classifications of parts and assemblies with specific manufacturing levels in production. They are to some degree, work-instruction drawings.

Design and material definition should be truly regarded as aspects of planning and drawings should be further developed as virtually complete work instructions including A/C *work*. When A/C requirements, particularly vital points and dimensions and excess allowances, are included:

- checking and recording are clearly delineated as work just as much as marking, cutting, fitting, etc.
- excesses are adequately considered and are consistently applied, and
- the potential for human error is reduced; loft, fabrication and assembly workers no longer have to refer to separately prepared A/C requirements or depend upon recollections.

6.2 Mold Loft

Strictly speaking, loft processes should be subject to the same A/C scrutiny as marking and cutting in a part fabrication shop. However, mold-loft process variations are too small to significantly impact on merged variation during part fabrication. But, loft errors (mistakes, omissions, etc.) are of concern because they disrupt the A/C cycle.

Errors cannot be treated with classical A/C theory, i.e., they do not enter into variation merging equations. Therefore, for A/C purposes written procedures should be developed in order to address:

- classifications of errors, and
- methods for checking, recording and analyzing (the statistical principles described in Appendix B could be used).

Further, qualified people should be assigned as specialists to do the checking. Loft defect lists and graphic representations of frequency of occurrence, as shown in Figure 6-1, are control mechanisms used by A/C engineers.

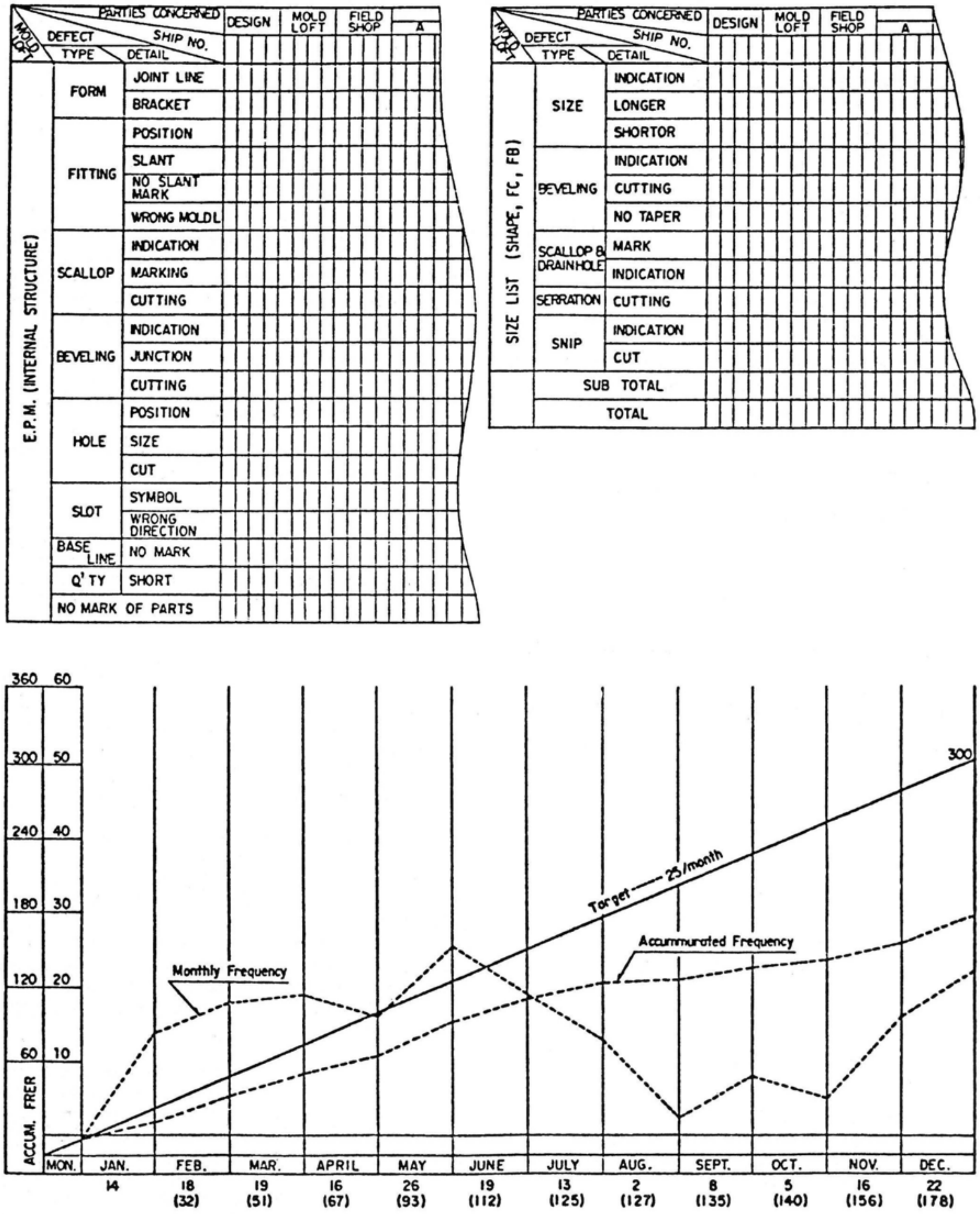
Each mold loft should be regarded as a nucleus for A/C activities because it generates most of what is used both for achieving and maintaining a specified degree of accuracy. Loft processes for producing N/C data, templates and other information formats should include essential A/C requirements such as:

- locations of vital points,
- calculated vital dimensions,
- calculated special dimensions which facilitate assembly and checking work,
- reference lines and check points,
- adequate marks for lay out marking (while most are sufficient for snapping a chalk line, there is difficulty in identifying which marks associate with each other).
- excess already incorporated (e.g., when workers do not have to separately mark an excess allowance, A/C is enhanced).
- more sufficient *bridging* instructions to minimize warpage and shrinkage during gas cutting.

6.3 Production Control

If just the terms *part fabrication*, *sub-block assembly* and *block assembly* are coded in a marking system for interim products, a relatively modern innovation to some, it is difficult to relate an explosion of vital points to an explosion of a hull into interim products. Further classifications of such products should be included in a marking system so that each interim product has a unique identity, e.g., by zone. In other words, a fully developed product-oriented work breakdown structure is essential for effective A/C planning, executing and evaluating.

Via product orientation, designers can respond more readily to production control requirements for work instructions. The latter are more than just detail drawings because they define interim products and specific sequences for their manufacture. With information so organized designers can more readily respond to A/C requirements to include, for example, tolerance limits and vital points in work instructions. Providing such information in work instructions, because they are the most universally employed documents, facilitates mutual understanding of A/C requirements and more efficient execution by loft, fabrication and assembly workers as well as by members of the A/C group.



MOLD LOFT	DEFECT		PARTIES CONCERNED / SHIP NO.			
	TYPE	DETAIL	DESIGN	MOLD LOFT	FIELD SHOP	A
E.P.M. (INTERNAL STRUCTURE)	FORM	JOINT LINE				
		BRACKET				
	FITTING	POSITION				
		SLANT				
		NO SLANT MARK				
		WRONG MOLDL				
	SCALLOP	INDICATION				
		MARKING				
		CUTTING				
	BEVELING	INDICATION				
		JUNCTION				
		CUTTING				
	HOLE	POSITION				
		SIZE				
		CUT				
	SLOT	SYMBOL				
		WRONG DIRECTION				
	BASE LINE	NO MARK				
	Q'TY	SHORT				
	NO MARK OF PARTS					

MOLD LOFT	DEFECT		PARTIES CONCERNED / SHIP NO.			
	TYPE	DETAIL	DESIGN	MOLD LOFT	FIELD SHOP	A
SIZE LIST (SHAPE, FC, FB)	SIZE	INDICATION				
		LONGER				
		SHORTOR				
	BEVELING	INDICATION				
		CUTTING				
		NO TAPER				
	SCALLOP & DRAINHOLE	MARK				
		INDICATION				
	SERRATION	CUTTING				
	SNIP	INDICATION				
		CUT				
	SUB TOTAL					
	TOTAL					

FIGURE 6-1: Defects or errors are not the same as variations. A/C engineers use mold-loft defect lists and graphic representations as aids for control of mold-loft errors.

In addition product orientation permits sufficient classification of the myriad of part and subassembly geometries in order to relate them to specific work processes. This association is critical for obtaining valid A/C data. Otherwise, work circumstances are insufficiently controlled and virtually no data sample will approximate a normal distribution. A/C as a science would not be applicable.

6.4 Fabrication

N/C gas cutting is almost universally applied by shipbuilders but there are still situations where semiautomatic cutters are useful supplements to N/C installations. More variation is probable in a semiautomatic process, therefore, A/C requirements should be different. However, there are common considerations when accuracy performances need to be enhanced:

- human engineering aspects apply, even for very advanced N/C systems,
- shrinkage allowances should be specified differently for different part classifications, e.g., parallel-edge part, internal part, etc.,
- kerf tolerances should be specified,
- maintenance and accuracy checks, more complicated for an N/C machine, should be performed regularly and frequently, worn torch-tips should be replaced and others cleaned,
- as heat deformation problems have not been totally solved, even where shipbuilding technology is most advanced, measurement data should be accumulated on the effect of different cutting sequences, bridge restraints, etc., and
- A/C engineers should be alert for cutting alternatives, e.g., lasers which can be focused, could perform with narrower kerfs, less heat input and thus less shrinkage and distortion.

6.5 Sub-block Assembly

Methods to control deformation, such as pretensioning, preheating and specified welding sequences, should be practiced. Regarding shrinkage, consider the panel for the sub-block shown in Figure 6-2. When the large plate is gas cut, shrinkage Δ_1, occurs because no bridges were provided across the cutouts. Additional shrinkage Δ_2 occurs when the large plate is welded to the small plate. Without a shrinkage allowance, the combined shrinkage $\Delta_1 + \Delta_2$ could necessitate rework, i.e., making the cutouts deeper during block assembly.

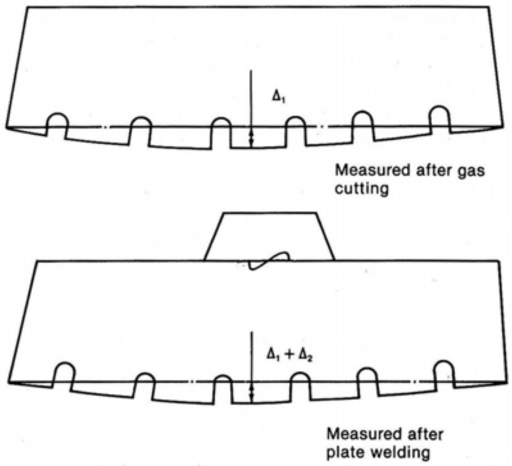


FIGURE 6-2: Work sequences impact on total shrinkage. If the two plates in the lower figure were welded together before gas cutting, the lower figure would reflect only shrinkage due to gas cutting.

In order to overcome such shrinkage:

- the two plates should be welded before gas cutting,
- bridges should be used across cutouts,
- *all* stiffeners and face plates should be fitted to the web before welding commences, and
- welding should conform to a prescribed sequence.

Further, deformation such as caused by welding should be diminished by pretensioning and/or removed by line heating.

Fitting processes for sub-block assembly are mainly performed manually. Where A/C is ongoing, there is indispensable close association between supervision of sub-block assembly work and the A/C engineer assigned to the sub-block assembly section (perhaps in a small shipyard assigned to the hull construction department). Because of preoccupation with variations in each work process and how they merge, the A/C engineer readily detects situations where simple jigs enhance both accuracy and productivity. More such jigs should be used.

6.6 Block Assembly

All of the preceding suggestions for sub-block assembly should also be applied in block assembly. During this stage, because it is just before erection, checking for accuracy is very critical. The checks should include alignments of platen and pin-jig foundations and means for positioning plates to form the panels upon which blocks will be assembled. Regarding curved blocks, pin-jig heights should be checked. After a curved panel is assembled, marked, checked and finish cut, the positions of its curved edges should be carefully checked. Further, simple jigs should be used to fix end positions of longitudinals and their angle of inclination.

6.7 Standardization

Standards infer conservatism. Quite the opposite is true particularly for A/C matters. A standard is simply a description of an authorized and currently practiced condition which is a baseline for comparing proposed improvements. Thus standards are means for a shipyard, as an entity, to know what it is doing and where it is going in shipbuilding technology matters. Adequate standards, in numbers and content, and sufficient specialists to modify, create and cancel standards are necessary for continuously improving productivity. Many shipbuilding problems can be solved by developing standards for:

- accuracy,
- excess and shrinkage allowances, and
- work flows and work processes.

6.8 Accuracy Standards

Because they are expressed as both standard ranges of accuracy normally encountered and tolerance limits beyond which rework is required, accuracy standards can describe a shipyard's potential for complying with tolerances specified for end products.

Just as much as accuracy standards are baselines for evaluating proposals to improve productivity, they are baselines for improving accuracy in an end product. If accuracy standards and an ongoing A/C organization which supports them are approved by a classification society, reapprovals for additional ship construction are usually unnecessary. See Appendix D.

6.9 Excess and Shrinkage Allowance Standards

Excess is an essential concept for successful application of A/C to hull construction processes. However, the amounts should be based on analyses of actual data which reflect the shipyard's experience. Excess amounts statistically derived, are based on the probability that for a high percentage no rework will be required. Thus, applying excess is an attempt to exactly compensate for normal variations caused by work processes which lead to variations in joint-gaps to be welded during erection. There must be understanding that a small percentage will require rework by gas cutting and/or backstrip welding.

Excess is generally thought of as a means for extending the edge of a plate to compensate for shrinkage. However, its use elsewhere should be specified such as for facilitating the fit of stiffeners between longitudinals; see Figure 1-4.

6.9.1 Elements of Shrinkage Allowance

- Shrinkage allowance is required to maintain the specified shape and dimensions at hull erection. The amount of shrinkage allowance for gas cutting, welding and/or line heating should be derived from data collected during shipyard operations.
- Shrinkage allowance is required for fillet welding internal members to shell plates (A). Shrinkage occurs in the direction normal to the welding line.
- Shrinkage allowance is required for removing welding-induced distortion by line heating after assembly work (B). This removes opposite-side indentations caused by fillet welding internal members. After assembly, heat is applied on the outboard side of the shell along lines which are exactly opposite the fillet welds. Shrinkage occurs in the direction normal to the heating lines.
- Shrinkage allowance is required for welding plates to form the panel on which a block is assembled (E).
- Shrinkage allowance is required for fillet welding stiffeners, e.g., flat bars and brackets to internal members such as a web plate (a).
- Shrinkage allowance is required for line heating on sub-assemblies, such as webs, to remove the indentations caused by welding (b).
- Shrinkage allowance is required for welding plates of internal members such as webs (e).
- Shrinkage allowance is required to compensate for welding and line heating other miscellaneous interim products, i.e., parts, blocks of special shape, etc.

6.9.2 Ways to Distribute Excess

There are two practical ways to predict the excess needed to offset shrinkage as described in the foregoing:

- Provide excess amounts only at edges of a block without regard for apportioning excess between block internals. Thus, the dimensions needed for layout are readily obtained from design drawings. However, the final positions of the internals will be different from specified design.
- Distribute excess proportionally taking into account shrinkage rates expected to be caused by each work process and the relative spacing of block internals from each other and panel edges. This method requires recalculating the dimensions needed for layout, but the final positions of internals will more accurately conform with design.

6.9.3 Ways to Distribute Excess vs. Assembly Sequences

Sequences for assembling a block, consisting of a panel stiffened by longitudinals and webs, can be classified as *"egg-crate"* or *"weld longitudinals to panel first"*. The work sequences are different as shown in Figure 6-3. Thus, the shrinkages caused by welding are sequenced differently. This is important because restraints are different, the heat input for different welds varies and regions which have been shrunk before do not shrink the same amount, even for the same heat input, during subsequent welding. Thus, the pertinent data that shipbuilders collect should be classified to match one or more of the four assembly alternatives depicted in Figure 6-4.

6.9.4 Standards for Work Processes and Information Flow

In order to establish effective standards, the role of each fabrication shop and assembly section must be carefully reviewed for its impact on production process flow. The inputs and outputs of each should be clearly defined and consistent with a single A/C system. In other words, everything on the right side of the variation merging equation must be compatible in order to obtain the best productivity for the entire hull construction process.

There cannot be dependence on just parochial knowledge. Written work processes which regard each other are essential for achieving specified accuracies and uniform flows of work and information. Standard processes also make it easier to change jobs and are a great aid for training. When a process standard is revised to incorporate an improvement, related others should be reviewed and/or revised as necessary.

The following guidance applies to standards which should be established:

- *standard practices for*
  - working instructions
  - lofting
  - fabrication (marking, gas cutting, bending, line heating)
  - sub-block assembly
  - block assembly
  - shipwright work
  - welding

- *A/C contents of standards*
  - check points
  - dimensions to be checked
  - checking methods
  - tolerance limits
  - checking procedures for jigs and machinery
  - feedback and remedial measures

- *examples of standards for block assembly*

for a flat block
- plate arrangement (positioning, match mark)
- welding (misalignment, gap)
- panel marking (diagonal length, width, straightness)
- holes

for a curved block
- supporting jig (normality, height)
- plate arrangement (jig position)
- datum line for joining
- block marking (four edges, diagonals)
- holes

"EGG-CRATE" WORK SEQUENCE	"WELD LONGITUDINALS TO PANEL FIRST" WORK SEQUENCE
1. Panel Assembly (E)	1. Panel Assembly (E)
2. Panel Marking	2. Panel Marking
3. Egg-crate Assembly (a,b,e)	3. Longitudinals to Panel Welding (A)
4. Egg-crate to Panel Welding (A)	4. Other-internals Welding (A,a,b,e)
5. Line Heating (B) if necessary	5. Line Heating (B) if necessary

FIGURE 6-3: When assembly sequences are different, the sequences of shrinkage and the amounts of shrinkage differ. Fitting problems will occur if different shrinkages are not anticipated. The parenthesized letters designate pertinent descriptions in Part 6.9.1.

for fitting

- elimination of welding-bead rise where internals cross panel joints
- gas cutting (notch, roughness, check line)
- end of web position
- end of frame position
- angle of internals relative to a panel
- collar-plate fitting
- misalignment and gap where internals join each other

grinding

- bead removal for rework
- bead removal to free temporary fitting

line heating

- block interface edges
- specified temperatures
- specified locations
- fairing

EXCESS DISTRIBUTION	ASSEMBLY SEQUENCE
Only At Panel Edges	Egg-crate
	Weld Longitudinals To Panel First
Proportionally Throughout	Egg-crate
	Weld Longitudinals To Panel First

FIGURE 6-4: There are two possible assembly sequences for each of two methods for excess distribution.

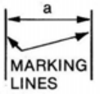
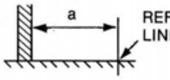
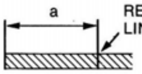
TEST DESCRIPTION (LINE THICKNESSES 1mm)		STANDARD DEVIATION
	a<1,000 mm a>1,000 mm	σ = 0.5 mm σ = 0.6 mm
	a<1,000 mm a>1,000 mm	σ = 0.4 mm σ = 0.4 mm
	a<1,000 mm	σ = 0.4 mm

FIGURE 6-5: Tests of measurement methods by one firm indicated that even folding rules do not cause significant variations. However, each shipyard should perform similar tests.

6.10 Measuring

Some variations are inevitable due to differences in:

- measuring methods,
- environments,
- work circumstances,
- reading judgments, etc.

One shipbuilding firm conducted tests of measurements obtained with folding rules that are popular among shipbuilders. Of all devices, folding rules were suspected of causing the most measurement variation. The results, shown in Figure 6-5, indicate that even their use does not significantly contribute to merged variation. However, each shipyard should verify its own measuring capabilities.

6.11 Photographs of A/C Practices

Figures 6-6 through 6-15 illustrate A/C ideas already employed by shipbuilders to control accuracy and simultaneously enhance productivity.

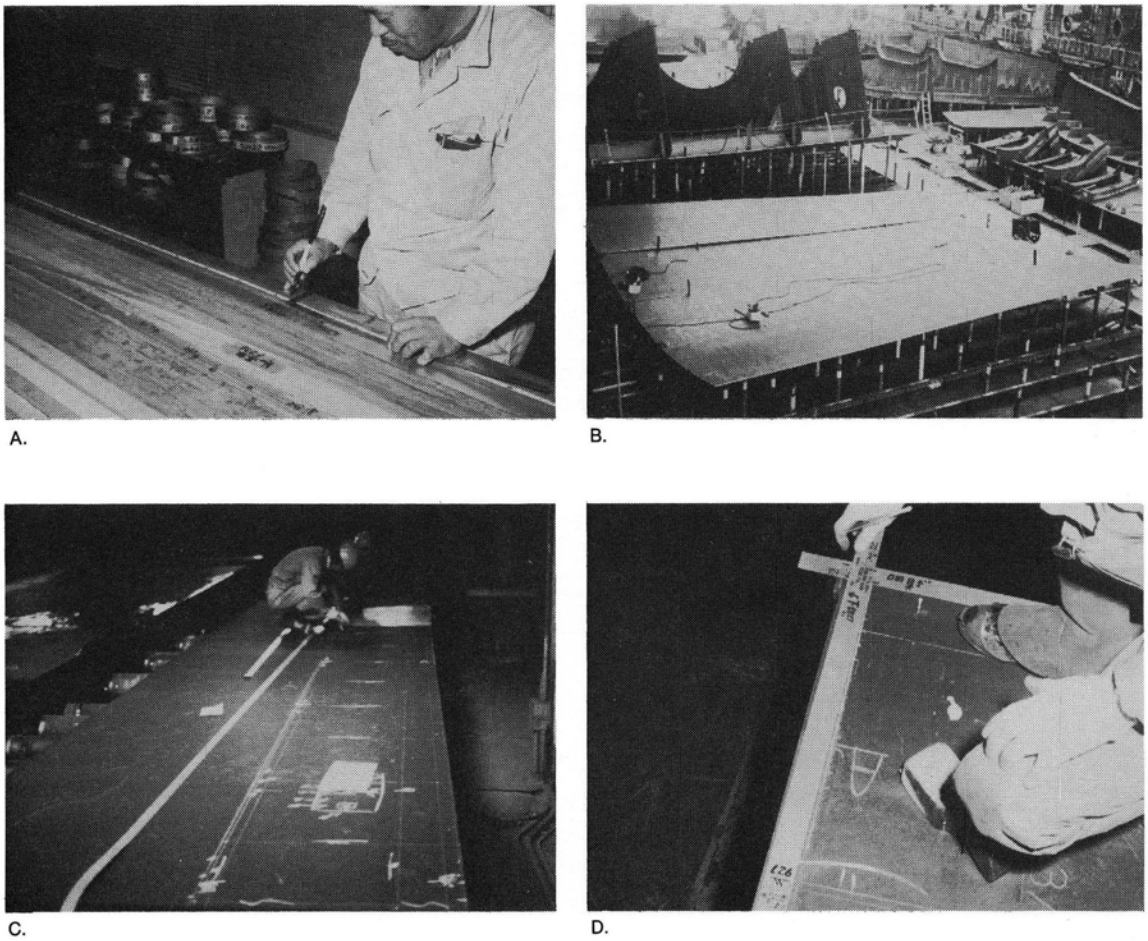


FIGURE 6-6: A. Layout tapes are prepared by loftsmen on a long table having a ruler fixed to its surface. A loftsman, reading a work instruction drawing, marks only locations and legends of interest. As shown in the background, identity of a specific application is on the reverse side of each tape. The tapes are of special-tempered steel so that they easily coil and when released readily lay flat. A light coating both prevents rusting and provides a good contrast for marks.

B. Tapes are for layout of overall dimensions, diagonals to confirm rectangularity, and positions of block internals after plates are welded together to form a panel as shown.

C. Even where N/C capabilities exist, tapes are also used for the layout of certain parts, e.g., parts for non-parallel midbody of a custom-designed ship.

D. Part fabrication and assembly workers simply transfer marks from tapes to plate and panel surfaces. They are not burdened with the need to interpret blueprints nor are they encumbered with irrelevant dimensions which appear on rulers.