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"Movable Bridges versus Murphy's Law"

MOVABLE BRIDGES VS. MURPHY'S LAW: AVOID HEADLINES BY ESTABLISHING "ACCOUNTABILITY CHECKPOINTS"

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"BRIDGE LEAF FALLS - NARROWLY MISSES EXCURSION BOAT!"

"BRIDGE COST OVER-RUNS PUT COMMISSION IN HOT SEAT"

"BRIDGE ENGINEER FINED, SUSPENDED FOR NEGLIGENCE"

"COMMUTER TRAINS BYPASS BRIDGE - 1 HOUR DELAYS"

"RADIO CONTEST: WHAT DAY WILL DELAYED BRIDGE OPENING OCCUR?"

Similar headlines to those shown above continue to be written and, when they do, no one wants the blame to fall on their shoulders. If not tragic, the stories behind these headlines can still be costly and embarrassing to bridge owners, employees responsible for maintenance and operations, contractors and design firms. Even when not at fault, reputations sometimes suffer due to association with a particular project.

There are a lot of things which can cause an unforeseen problem for a movable bridge. Design error is one. Construction method is another. Faulty materials can be a problem also. Maintenance after it is built is another possibility. Politics can enter in, causing a project to be unreasonably compressed within such a time frame as to influence an election, or can induce funding increases or reductions. Employees can make mistakes or can deliberately sabotage a structure. The general public has been known to commit improper acts as well. However, the thrust of this paper is only directed toward the work of the Mechanical Designer, Specifier and Shop Drawing Reviewer.

Before proceeding, though, it is probably best to define what is meant by "Murphy's Law". "Murphy's Law" is a concept described by the author Arthur Bloch in a book of the same title published by Price/Stern/Sloan of Los Angeles in 1977. The concept is named after a Captain Edward Murphy, Jr., who was in charge of a research team in the very early days (1949) of the National Aeronautics and Space Administration (NASA). In this research at Edwards Air Force Base in California, a Major John Paul Stapp had agreed to subject himself as a human "guinea pig" to tests of endurance under increased gravitational forces which were produced by riding a rocket powered sled across the desert [People Magazine, January 31, 1983]. He had already successfully experienced 31 G's, that is, 31 times the gravitational force of the Earth at sea level, during these tests. A test in which even higher G-forces were produced was executed some time later, almost executing Major Stapp in the process. Afterwards, knowing that his experience on the sled in this last test had probably defined the ultimate limit of human endurance, the Major Stapp asked what the maximum reading had been on the instruments. To this query, the red-faced technician was forced to reply, "Zero, Sir!" - the gages had been wired backwards during the test! In an attempt to rescue his man from the other officer, Captain Murphy said something to the effect that, "If something can go wrong, it will." To this, the Major thundered, with possibly a few other choice words, "THAT'S MURPHY'S LAW!"

Indeed it is. In this paper we will call it "Murphy" for short, with the understanding that when "Murphy" is mentioned I refer only to the concept, with no reference intended toward any individual or surname.

As so defined and disclaimed, our first challenge is to keep "Murphy" "off our team". To do this, we designers, reviewers, and inspectors attempt to assure ourselves that nothing is left to chance in our work. But one place "Murphy" can show up, and frequently does, is between areas of responsibility. You might keep him off your team, but what can you do you to keep "Murphy" "off the field"? As a Designer, Specifier or Reviewer, can we join with others (or induce them) to help us keep "Murphy" away?
The trouble is, "Murphy" is adept at making room for and concealing himself within a project. He has a lot of "helpers", too, which enable him to be more likely to do this. Some of these are the following:

- PRICE PROPOSALS FOR ENGINEERING/PROFESSIONAL SERVICES
- "NOT MY JOB" ATTITUDE
- LACK OF COMMUNICATION
- LACK OF PLANNING
- LACK OF ACCOUNTABILITY
- TIGHT BUDGET
- TIGHT SCHEDULE
- MULTI-ENTITY ENGINEERING RESPONSIBILITY

Some of "Murphy's helpers" can be avoided, others we can only learn to live with. In the same way, however, "Murphy" has some opponents which can be made available to help us. These include:

- PROFESSIONAL PRE-QUALIFICATION OF CONSULTANTS BY CLIENTS
- ATTITUDE OF PROFESSIONALISM
- PRIDE IN WORKMANSHIP
- PLANNING
- ACCOUNTABILITY
- COMMUNICATION
- REASONABLE BUDGET
- REASONABLE SCHEDULE
- TURN-KEY ENGINEERING RESPONSIBILITY

To this list of "Murphy's Opponents", add the term "ACCOUNTABILITY CHECKPOINTS", with the following definition:

> "Accountability Checkpoints - Locations of transitions or ambiguities in responsibility, for which effort is made to further define or cover such responsibility, particularly through communication and checking."

Based on experience, the Designer/ Specifier/ Shop Drawing Reviewer and the Inspector can establish and utilize these Checkpoints in transitional areas of the work to minimize the possibility of something "falling through the cracks." As Mechanical Specialists, we have great opportunity in this area, and it comes under the umbrella of PROFESSIONALISM.

Somebody is asking, "Why should I worry about other areas of responsibility - I have enough problems of my own! And I don't want to take on any more liability!" The concern about additional liability for Mechanical Specialists is certainly valid in today's society. For this very reason it is important for us to assign responsibility in the Plans and Specifications and, in so doing, communicate where our responsibility ends.

HOW CAN I, AS A MECHANICAL SPECIALIST MEET THE "MURPHY" CHALLENGE?

As previously discussed, the goals we want to deal with as a Mechanical Specialist include not only KEEPING "MURPHY" OFF THE

TEAM, but also KEEPING "MURPHY" OFF THE FIELD. Referring to the definition of an "Accountability Checkpoint", FOR MECHANICAL DESIGNERS/ SPECIFIERS/ SHOP DRAWING REVIEWERS this means locating transitions and possible ambiguities in responsibility in the mechanical portion of the job which might occur during the Contract. Means should be found to further define or cover such responsibility, particularly through communication and checking.

During the design phase, a Project Manager must coordinate the Structural, Mechanical and Electrical work to ensure that all work designed and specified is compatible. Within the various disciplines, including Mechanical, careful attention must be paid to calculation and detail, as well as to concept. This and other in-house quality assurance ensures that "Murphy" is kept off the design team. In communicating the design to the Contractor, however, "Accountability Checkpoints" can begin to come into play to accomplish the purpose of keeping "Murphy" off the entire "field". Some of the tools and methods available to the Designer/ Specifier are the following:

1. IDENTIFY MECHANICAL CRITICAL INTERFACES

During the design, critical interfaces between components should be identified. These may include the following. The majority of these items define transitions in responsibility as well as physical interfaces. These transitions in responsibility are shown by the listing of interfacing parties in parenthesis:

A. Shaft journals at bearings (Shaft Manufacturer - Bearing Manufacturer - Mechanical Installer)

B. Gear wheel mountings on shafts, including keys (Gear Manufacturer - Shaft Manufacturer)

C. Rack joints (Rack Manufacturer - Installer)

D. Components within commercial units and assemblies (Assembled Unit Manufacturer - Component Supplier - Designer/ Specifier)

E. Custom fabricated components connected to commercially manufactured components (Fabricator - Commercial Manufacturer)

F. Hydraulic motor connected to hydraulic power unit and machinery shaft (Hydraulic Component Manufacturer - Hydraulic Power Unit Manufacturer - Shaft Manufacturer - Hydraulic Installer - Machinery Installer)

G. Machinery connections to structure (Machinery Installer - Structural Fabricator - Structural Erector)

H. Electrical connections to machinery (Machinery Manufacturer - Machinery Installer - Electrical Installer)

Figure 1 is a flow chart showing basic responsibility within many new bascule bridge construction projects. (The Owner's role is omitted for clarity.) Figures 2 and 3 show further development of this chart.

Figure 2 shows some of the shared responsibilities defined by the critical interface listing above. Each of these presents an opportunity for "Murphy" to enter the "field". The challenge is to develop and operate an effective "Accountability Checkpoint" in each case.

As a first step, the Designer/ Specifier should be very specific in the Plans and Specifications to indicate exactly what is physically and operationally required at each critical interface. For the items listed, some of the ways this can be done are shown in Figures 4 and beyond. The actual work may become more definitive by doing this, but no additional means of accountability is added to the charts by this step alone.

"Accountability Checkpoint" Requirements within the Contract for additional communication and checking can help to coordinate the various entities and to define interfacing responsibilities to a greater extent. The purpose is to not only give the Contractor something to physically adhere to in the Plans and Specifications, but to cause additional checking to occur. An "Accountability Checkpoint" is established when a particular interface must be discussed or checked by one to the satisfaction of another, beyond normal communication or checking. There must be an agreement between the two entities that the <u>intent</u> of the Contract is met, or that the interface is satisfactory to both components or parties.

Referring to Figure 3, one method shown which has been typically used successfully in the past is the Shop Drawing Review. This method can be very rudimentary, however, and what is sometimes a very limited scope can often be improved. There can be a tendency for components to be reviewed individually without enough concern given to the installation. Another tendency is to review a commercially manufactured assembly without enough priority given to individual components within that assembly. The Mechanical Shop Drawing Reviewer is normally a member of the design firm, as shown on Figures 1 through 3, but this function is sometimes taken over by the Owner, as indicated by Figures 4 through 6. In the latter case there is more chance that compatibility or installation problems may occur since some concerns of the designer may be inadvertently ignored during the review.

2. SHOP DRAWING REQUIREMENTS

Shop Drawings should be required for every custom fabricated component, and Certified Catalog Information should be provided for every commercially manufactured component.

The name of the actual manufacturer should be provided for all components integral to an assembly, and for the assembly itself.

Not only should information on components be provided, but drawings should be provided showing the location of the components within the assemblies. Also, drawings showing installation and assembly at the site should be furnished.

3. REVIEW PROCEDURES

As the Contractor begins to submit Shop and Assembly Drawings, the Reviewer can also contribute to keeping "Murphy" off the field. If the Contract includes certain "Checkpoints", his mission is clear as to this regard. But even if no "Checkpoints" have previously been established, the Reviewer can establish his own, within the limits of his authority. These may cost him an hour or two more time within the job, but tremendous insurance is secured thereby toward the success of the project and the protection of his firm.

For the Reviewer, the identification of critical interfaces and details is, once again, key to "keeping Murphy off the field". While Specifications should have made the Contractor accountable for compatibility of components (Figure 5), the Shop Drawing Reviewer should take care to note any obvious compatibility problems and call them to the attention of the Contractor. Not only should compatibility be confirmed at interfaces between mechanical components and suppliers, but structural and electrical interfaces with the mechanical components should also be investigated. This is not to take away the Contractor's responsibility, however. Any discrepancy found should only be pointed out to the Contractor for his correction. Details and compatibility should remain within the Contractor's responsibility. Anything the Reviewer finds and calls attention to should be considered only a courtesy to the Contractor. However, benefits obviously accrue to the Design Firm or Owner, as well.

During the review process, the Reviewer should be communicating with both the Designer/ Specifier and the Contractor. Not only should any question concerning the intent of the Specification or Plans regarding design be addressed, but any question regarding the intent of the requirements for submittals should also be discussed. This is particularly the case for commercially manufactured equipment.

4. OTHER "ACCOUNTABILITY CHECKPOINTS"

Figures 7 through 10 show some other examples of how a Specifier may establish "Accountability Checkpoints" in the Plans and Specifications. Refer to Figures 3 and 6 to see how the establishment of these "Checkpoints" can affect the lines of communication during the project. The best way to describe what this concept accomplishes is to compare the corresponding flow charts (with and without additional lines of communication) to electrical circuits with and without servo feedback. While each is designed to provide control, the "feedback" type circuit not only <u>directs</u>, but also <u>confirms</u>.

A. SHOP TESTING REQUIREMENTS

Certain components should be tested in the shop. The extent of such tests and the documentation required will vary. An example of such a requirement from a specification is shown in Figure 6.

B. FIELD SUPERVISION REQUIREMENTS

Requirement that a manufacturers engineer or representative be present during installation may be advisable due to the complexity or critical nature of a component or assembly. (See Figure 7).

C. FIELD TESTING REQUIREMENTS

Special field testing requirements may be required for certain components or assemblies. (See Figure 8).

D. CONTRACTOR RESPONSIBILITY

A statement that ultimate responsibility for compatibility and performance rests with the Contractor should be part of the Contract. (See Figure 9)

E. STATEMENT OF COMPATIBILITY

Contractor should be required to state in writing that components are compatible with all other components and that they meet the requirements of the Plans and Specifications. (See Figure 10)

CASE STUDIES

We have all had experiences with "Murphy's Law." For discussion, here are a few such cases in which Hazelet + Erdal was called for consultation. "20-20 hindsight" is hereby acknowledged. Therefore the comments made here should not be taken as criticism of anyone involved in the cases cited. Rather, the goal is to improve our own "foresight":

<u>CASE I:</u> Chicago Type Trunnion Bascule Bridge (not in Chicago)

INCIDENT: During rehabilitation, several turned bolts holding an internally geared lower rack section in place were sheared while the leaf was being lowered. Rack section was pushed away from the pinion several inches into its support girder at a location just below the joint with the upper rack. This occurred as pinion teeth disengaged and rode up on rack teeth causing crown-to-crown contact.

INSPECTION FINDINGS:

1. Contractor was not keeping the leaf in balance during construction and it was span-heavy. At reduced speed the operator was lowering the leaf only a short distance at a time, then shutting down the motors and setting the brakes to prevent the leaf momentum from becoming too great to control. Brake torques had been adjusted to maximum as a "safety" measure.

2. It was determined from field measurement that the rack was improperly fabricated and installed in 1926. The distance from the centerline of tooth to the joint on the lower rack section was approximately .25" short, and the rack sections were installed tightly at this joint. Apparently the rack was "worn in" over a short time and there was never any operational problem experienced.

3. Rack was improperly rehabilitated. Only the lower rack section was rehabilitated by building up and profiling the teeth by welding and shaping. The upper section was not rehabilitated. This exacerbated the original pitch problem since the lowest tooth on the upper rack was *worn on top*. *Rack design called for* a circular pitch of 7.5". Actual distance measured between faces of teeth on either side of the joint was 6.75". As leaf was being "held back" by the face of the last tooth on the upper rack section, the pinion rode up on the crown of the first tooth of the lower section.

ACTUAL DAMAGE: Rack damaged requiring repair by straightening and welding. Turned bolts destroyed require replacement in kind. Teeth damaged on both rack and pinion require restoration of profile by re-machining and welding. Construction delay.

POTENTIAL DAMAGE: Possible loss of entire leaf.

ACCOUNTABILITY CHECKPOINT RECOMMENDATIONS - ORIGINAL CONSTRUCTION:

Specify tolerances for critical dimensions on rack section and assembled rack pitch dimension at joint.

Require Contractor to submit Shop Drawing of rack sections showing critical fabrication dimensions.

Require Contractor to submit Assembly Drawing showing critical installation dimensions.

Specify requirement for shop inspection with certification.

Specify requirement for field inspection with certification.

ACCOUNTABILITY CHECKPOINT RECOMMENDATIONS - REHABILITATION:

Specify complete rehabilitation of rack and pinion, retaining original design dimensions requirements.

Specify that Contractor shall keep bridge in balance at all times.

Require Contractor to submit Shop Drawing of rack section rehabilitation showing critical dimensions.

Require Contractor to submit Assembly Drawing showing critical installation dimensions, particularly across joint.

Specify requirement for field inspection, at critical interfaces, with certification.

CASE II: Chicago Type Trunnion Bascule Bridge (not in Chicago, same bridge as above).

INCIDENT: During rehabilitation, cap of bearing next to rack pinion pops off.

INSPECTION FINDINGS: Grit had accumulated in truss during sand blasting operation. When bridge was lifted for navigation, sand slid down sloping surface of truss and collected in racks. As bridge was lowered, rack pinion was forced out of alignment with rack by accumulated sand. This caused the pinion shaft to force the cap off the bearing.

ACTUAL DAMAGE: Popped bearing cap. Bearing cap bolts broken. Construction delay.

POTENTIAL DAMAGE: Possible loss of entire leaf.

ACCOUNTABILITY CHECKPOINT RECOMMENDATIONS - REHABILITATION:

Specify that Contractor must submit for review a plan of construction staging.

Specify periodic inspection with documentation of conditions during construction.

Specify requirement for inspection with documentation in Construction Log prior to operation during construction.

ADDITIONAL RECOMMENDATIONS - ORIGINAL CONSTRUCTION:

Design truss and rack details which will not tend allow accumulations of foreign material.

<u>CASE III:</u> Double Leaf Strauss Bascule Highway Bridge

INCIDENT: During bridge lift for navigation, one leaf collapses into channel just after pleasure craft have passed and just prior to intended passage of large sightseeing excursion boat.

INSPECTION FINDINGS:

1. Counterweight trunnion had moved axially within its bearing during operation. Hanger for suspended counterweight had fallen off trunnion. This caused one end of counterweight to lose its connection to leaf. Leaf initially deformed, counterweight hanger on other side of counterweight was spread due to loss of first hanger. The entire counterweight then fell into the pit. This resulted in the unbalancing of the leaf, causing it to collapse.

2. Trunnion shop detail was different from design detail. Per design, a keeper plate was to be keyed into a slot on the trunnion. As fabricated and installed in 1928, slot was changed to D-shaped section which continued to the end of the trunnion pin. Instead of preventing axial movement in both directions, movement in only one direction was prevented.

3. At some point in the life of the bridge, grease was substituted for oil as the lubricant of choice in the lubrication schedule. A pipe plug which was necessary for retention of oil was not removed for the purpose of ensuring proper full length grease flow. Over time contaminated lubricant dried out and collected in the oil grooves with no way out. The trunnion eventually seized,

causing it to translate axially, thereby causing the resultant failure.

ACTUAL DAMAGE: Loss of leaf. New bridge required for replacement.

POTENTIAL DAMAGE: Loss of life.

ACCOUNTABILITY CHECKPOINT RECOMMENDATIONS - ORIGINAL CONSTRUCTION:

Specify that any design change must receive written approval by designer at any stage of the work.

Specify critical dimensions on counterweight trunnion and connection assembly.

Require Contractor to submit Shop Drawing of all components showing critical fabrication dimensions.

Require Contractor to submit Assembly Drawing showing critical installation dimensions.

Specify requirement for shop inspection with certification.

Specify requirement for field inspection with certification.

ACCOUNTABILITY CHECKPOINT RECOMMENDATIONS - MAINTENANCE AND OPERATION:

Owner to have policy of contacting a movable bridge engineering consultant when questions regarding operation or maintenance arise.

Owner to obtain second opinion from movable bridge consultant before changing maintenance practices.

Periodic inspection team to include identification and assessment of critical details as part of their work.

Maintenance group should develop and maintain a Logbook of Operation, and maintain and update Mechanical Maintenance Manual to document any changes in procedure throughout the life of the bridge.

Owner should consider the addition of an automatic Data Acquisition System (DAS) to the electrical system.

<u>CASE IV:</u> Double Track Railroad Vertical Lift Bridge

INCIDENT: Just before commuter train rush hour, bridge span seizes in partially raised position.

INSPECTION FINDINGS:

1. Trunnion bearings had seized. When caps were removed, gritty contamination was found in grease.

2. Grit also found in open can of grease. Upon analysis, grit traced to cleaning and painting operation 3 years before.

ACTUAL DAMAGE: Rush hour commuter rail traffic tie-up. Two-week emergency/reduced capability operation. Scored bushings require replacement in kind. Special sheave and rope support systems required.

POTENTIAL DAMAGE: Damage to other components by same grease. Much longer delays and reduced capability operation period.

ACCOUNTABILITY CHECKPOINT RECOMMENDATIONS:

Owner should maintain a Logbook of Operation. Operator would be required to enter certain information concerning operational characteristics during at least one opening each shift. One of the items would be power required to operate, for which a sudden or steady increase may indicate developing problems. Logbook should be periodically checked by supervisor.

Maintain a Logbook of Maintenance, documenting inventory as well as dates of lubrication and servicing.

Maintenance should take care to protect all stored lubricants during rehabilitation. An up-to-date inventory should be maintained, and a special inventory should be taken prior to start of construction and subsequent to completion. This would not only reveal contamination, but could reveal any shrinkage of inventory during the construction phase.

Personnel should inspect lubricant condition before applying.

Consider addition of automatic Data Acquisition System.

CONCLUSION

As seen above, the key to establishing "Accountability Checkpoints" is being able to identify areas of ambiguous or transitional responsibility, and to adequately define who actually is responsible under the Contract. As professionals, we owe it to ourselves if not to anyone else.

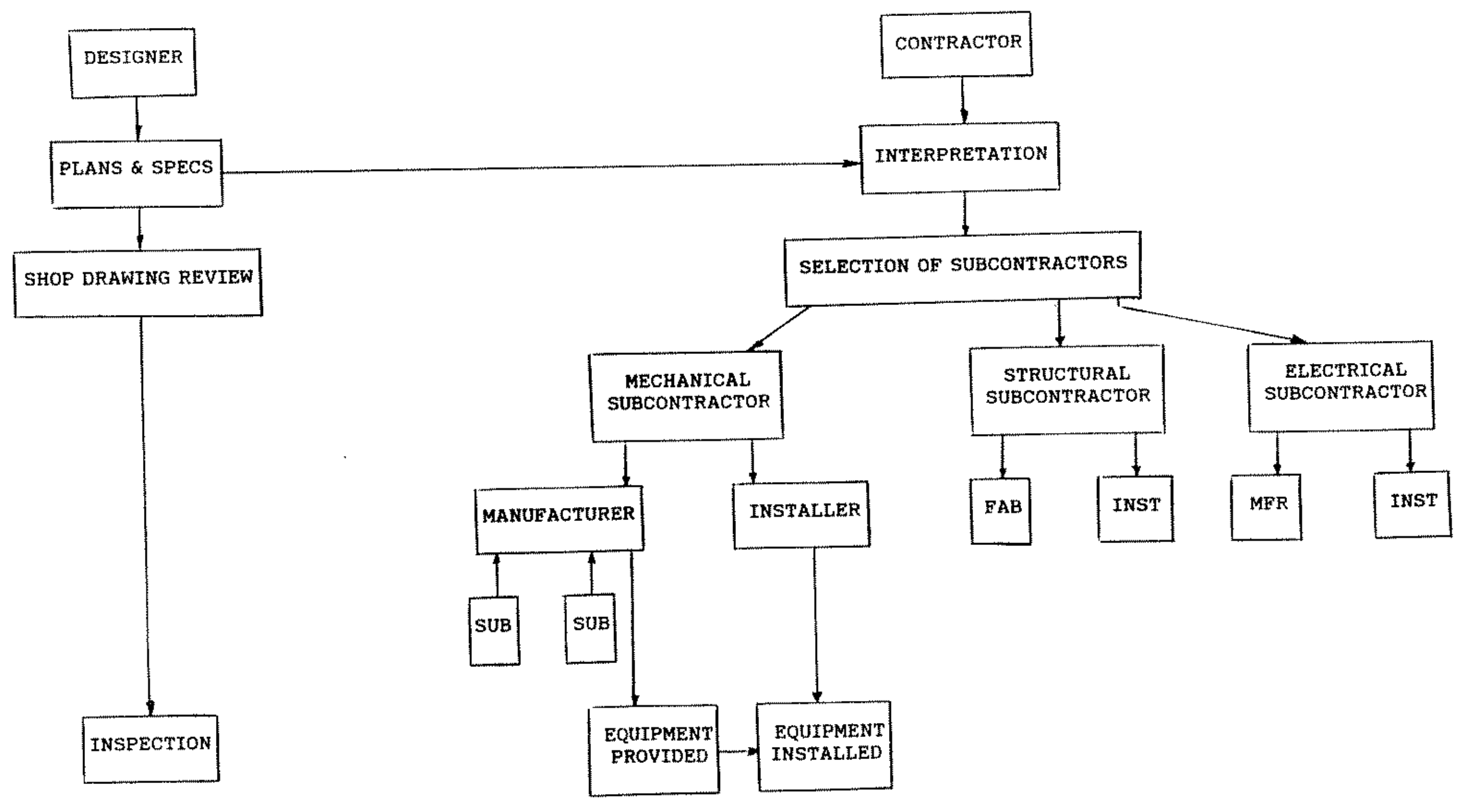

FIGURE 1

BASIC PROJECT ORGANIZATION
UNDER CONTRACT

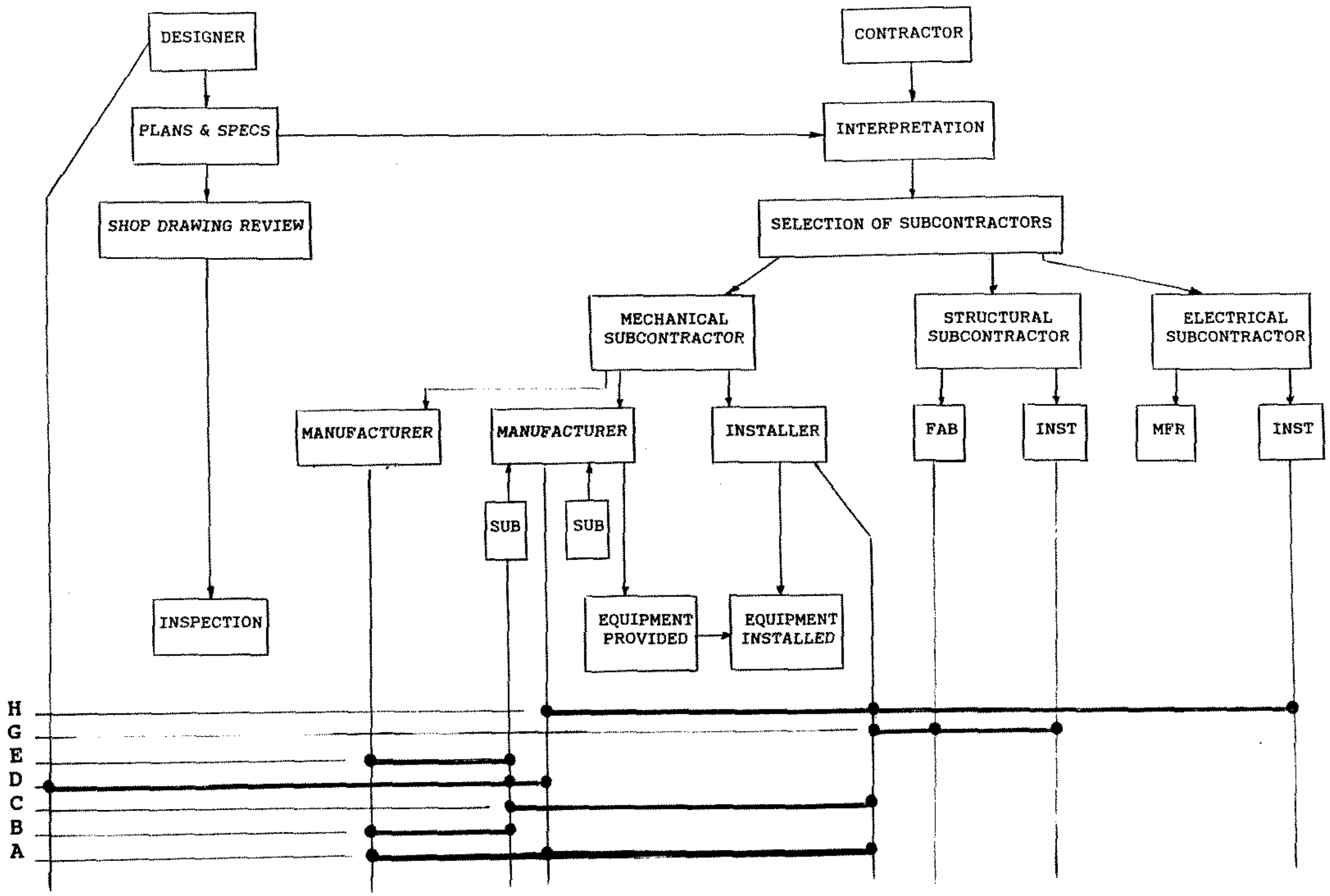

FIGURE 2

FLOWCHART SHOWING SHARED RESPONSIBILITIES
(SEE TEXT, PAGE 5)

LEGEND

CC CATALOG CUT
ID INSTALLATION DRAWING
WD ELECTRICAL WIRING DIAGRAM
CD ELECTRICAL CONDUIT DIAGRAM
SD SHOP FABRICATION DRAWING
MC MECHANICAL CALCULATION
AD ASSEMBLY DRAWING
ST DOCUMENTATED SHOP TEST
FI DOCUMENTED FIELD INSPECTION
ME MANUFACTURER'S ENGINEER PRESENT DURING INSTALLATION

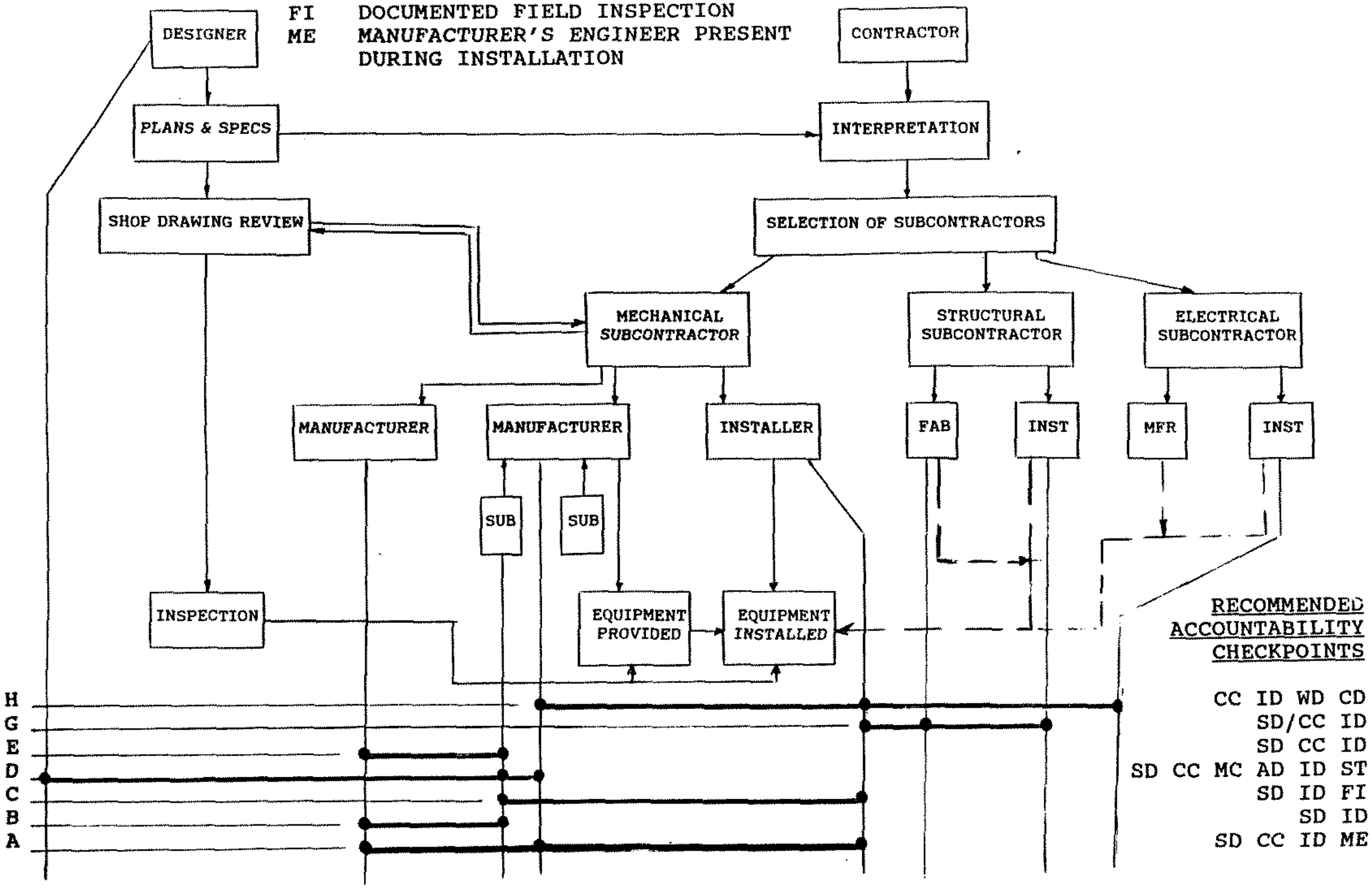

FIGURE 3

RECOMMENDED ACCOUNTABILITY CHECKPOINTS AND MAJOR INTERFACES