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Fire-Safety Upgrades in Airport Control Towers

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Abstract: This paper discusses fire-safety upgrades and the various aspects of their design and construction in standard airport traffic control towers (ATCTs) for the Federal Aviation Administration (FAA) in the Western Pacific region. Towers provide a safe and orderly flow of airport traffic for the benefit of the flying public. Knowledge of ATCT fire-safety upgrades can benefit professionals and contractors in various engineering fields, especially those interested in project management and control techniques. Specifically, the successful upgrading of 35 standard towers in the Western Pacific region to provide smoke-free, fire-protected means of egress and early-warning fire detection and alarm system, as specified in FAA's *Fire Safety Guidelines*, demonstrates how to meet major program objectives within a cost-effective time frame. This paper includes a brief history of the relationship between the FAA and the Technical Support Services Contract as it relates to these upgrades; a general description of the work required by the FAA; and a review of project organization, communications, design methodology, cost/scheduling, procurement, construction, major challenges, and recommendations for future upgrades.

INTRODUCTION

The Federal Aviation Administration (FAA) was directed by the U.S. Congress and Occupational Safety and Health Administration (OSHA) to correct fire-safety deficiencies in all towers across the United States, since they did not meet acceptable fire-safety standards of OSHA. These towers were upgraded based on general criteria in Fire Safety Guidelines. FAA's *Fire Safety Guidelines* (1991) are a compendium of national and OSHA codes and regulations. These guidelines comprise two sections, survey and evaluation. Essentially, all towers were required to have a smoke-free, fire-protected means of egress and to have an early-warning fire-detection and alarm system.

The primary intent of the OSHA program was to provide at least one enclosed exit stairway either pressurized in case of fire, or arranged as a smoke-proof enclosure. Other significant objectives included a complete automatic detection and alarm system to provide early warning to the tower occupants, and additional safeguards to limit the spread of fire and smoke.

The program was limited to the aforementioned scope, since these were the minimum requirements to protect Federal Aviation Administration (FAA) personnel working in the towers in the event of fire. It was not possible to bring the entire facility to the current codes due to the retrofit nature of the project and cost constraints.

Some of the major fire-safety deficiencies found in towers included (but were not limited to), non–fire-rated paths of egress, inadequate fire-alarm and detection systems, and non–smoke-proof enclosures. To implement the OSHA modifications, the FAA delegated these responsibilities to fire protection and architecture/engineering (A/E) firms. A selected number of standard towers were surveyed by the licensed fire-protection engineers to develop generic abatement drawings. (Towers were built to a national standard design. The purpose of standardization was to use the same generic design that can be adapted at various sites. However, current towers are designed based on the specific needs of airports.) The generic abatement drawings were developed for the following eight types of standard towers:

1. Hunt (with and without elevator)
2. Avco (with and without elevator)
3. Goleman-Rofle
4. Mock
5. Pei
6. Type O
7. Welton Becket
8. Air-A-Plane

The generic design, along with *Fire Safety Guidelines*, were used for adapting the drawings for various tower sites. *Fire Safety Guidelines* were common to all standard towers, and the tower type had no bearing on fire-safety upgrades. The existing condition of each tower dictated which details applied, and what modifications needed to be made. Common details applied to several towers, due to similarities in architectural and structural features.

These OSHA upgrades for standard towers in the Western Pacific (WP) region which started in January 1991 were completed on schedule within budget in December 1992. Nationwide, 248 standard towers were upgraded at a cost of more than $40,000,000. The 35 WP region tower upgrades cost about $7,000,000. Approximately 140 nonstandard towers are in progress of being upgraded nationwide. Towers built to non-standard design are mostly owned by various cities and counties.

The OSHA upgrade project is a highly visible national program, mandated by the U.S. Congress. Thus, it was vital for program managers to meet the established completion dates.

The FAA entered into a Technical Support Services Contract (TSSC), with Raytheon Service Company (RSC), Burlington, Mass., as its prime contractor. RSC has teamed up with AECOM Technology Corporation Services (ATCS) as a subcontractor. ATCS is comprised of five firms. Of those five, Daniel, Mann, Johnson and Mendenhall (DMJM), Los Angeles, provides the major resource. The TSSC provides the FAA with engineering, construction, and installation services for implementing the national airspace upgrades. There are nine TSSC offices nationwide, headquartered in Washington, D.C.

When the writer took over the project, it was several months behind schedule. About 3 months before the completion date, the project's scope was increased approximately 20% without a corresponding change in the end date. The electronic communication equipment relocation for each site was developed as the project progressed. The project was incrementally funded; it had budgetary limitations; and, due to the retrofit

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nature of the project, there were problems inherent to both the design and the construction phases.

Nevertheless, the project was eventually completed within the FAA's time limits. Credit for the success is due to a coordinated effort by the FAA and TSSC personnel. The reasons for the success of the Western Pacific region project form the basis of the present study.

Site Locations

The Western Pacific region administered by the FAA includes California, Arizona, Nevada, Hawaii, and various Pacific Islands (Fig. 1). The project was administered and controlled from the head office located in Los Angeles.

Types and Aspects of Standard Towers

For better understanding of the project, it is necessary to be familiar with the various types and features of standard towers.

There are eight different types of towers constructed to standard national design nationwide. However, the WP region has only seven types of standard towers (they have no Air-A-plane–type towers). These standard towers are named after architects or builders; in some cases, the FAA has given the towers their names. These towers have some similarities in architectural and structural features. They are also classified based on height, floor space, and occupancy levels. In addition to these towers, there are low-activity and intermediate-activity standard towers. Table 1 summarizes some of the different tower types, which are shown in Figs. 2–8.

PROJECT START-UP PHASE

Organization

To expedite the project and to enhance the interfaces, it was important to integrate the TSSC personnel and the FAA into one functioning team. Fig. 9 represents the combination of project organization that had line authority over functional activities, and a task force organization with personnel drawn temporarily from existing functional groups.

The TSSC WP organization maintained engineering and construction as two different departments managed separately by two supervisors. However, the standard tower team found it necessary to integrate engineering, construction, and installation into one organization for better control. The new design organization was based on a teaming concept, with a civil engineer/architect leading a group of electrical and mechanical engineers. The design team was supported by other technical staff as needed. There was constant interfacing between different engineering disciplines due to rapid scope changes and the retrofit nature of the project. The construction and installation group in the field closely interacted with the design group to minimize change orders, and implement proper design.

Communications

The restructuring of the standard tower organization improved the channels of communication. To further enhance

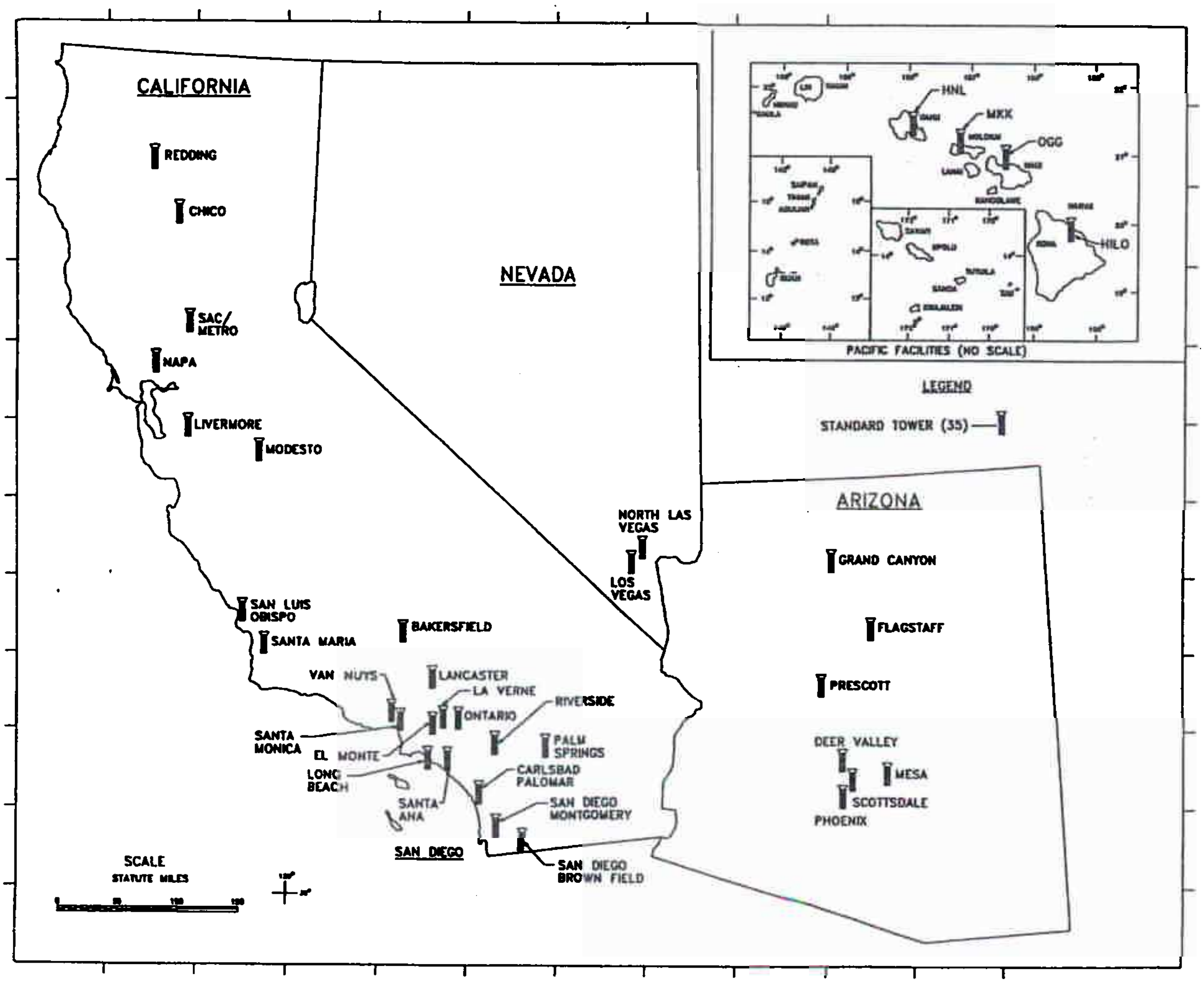

FIG. 1. Locations of 35 Standard Towers in Western Pacific Region

TABLE 1. Description of Tower Types

Tower (1)	Height m (2)	Height ft (3)	Construction (4)	Number in region (5)	Figure (6)
Welton Becket	50–55	165–180	Protected noncombustible	3	Fig. 2
Pei	36–38	120–125	Unprotected noncombustible	2	Fig. 3
Goleman-Rolfe	18–38	60–125	Protected noncombustible	3	Fig. 4
Mock	18–26	60–85	Unprotected steel and masonry	2	Fig. 5
Hunt	10–23	35–75	Exposed steel framing clad with corrugated metal wall panels	6	Fig. 6
Avco	13–21	45–70	Exposed steel framing clad with corrugated metal wall panels	6	Fig. 7
Type O	15–18	50–60	Exposed steel beams and concrete blocks	8	Fig. 8

FIG. 2. Welton Becket, Honolulu, HI

FIG. 3. Pei, Sacramento, Calif.

FIG. 4. Goleman-Rolfe, Ontario, Calif.

FIG. 5. Mock, Bakersfield, Calif.

FIG. 6. Hunt, San Diego, Brownfield, Calif.

the quality of communications in the WP region and to facilitate coordination between national and regional offices, the program manager implemented a monthly interregional coordination newsletter. The newsletter was a two-way communication channel and was prepared based on information received from various regions. The newsletter was in bullet format to avoid lengthy text and to communicate information clearly and efficiently. A database of information was created by tower type and by region to resolve design and construction problems and to avoid unnecessary duplication of work. Design discrepancies and construction difficulties were discovered and corrected, and then incorporated into future design packages. The newsletter also included a synopsis and progress of various towers, cost/schedule variances, funding, long lead materials, change orders and difficulties. The newsletter was an excellent communication tool and all the regions were encouraged to share information and ideas regarding all aspects of the program.

Nationwide monthly teleconference with key personnel from all the regions were conducted by the FAA to discuss various problems. Weekly teleconferences with construction and in-

FIG. 7. Avco, Phoenix Deer Valley, Ariz.

FIG. 8. Type O, Riverside, Calif.

stallation crews working at different sites were conducted by the WP program manager to discuss the progress of the project, and also to resolve problems. In the beginning, daily engineering staff meetings were conducted. However, the schedule was reduced to weekly meetings after engineers had become comfortable with their responsibilities. To expedite the contracting process, biweekly construction meetings were conducted with procurement. During these meetings, schedules were set and deadlines were laid down. The FAA was also invited to participate. All these efforts expedited the project progress and eliminated communication bottlenecks.

Project Control Systems

For the OSHA upgrade project, the cost/schedule data was an extract from a mainframe-based information management system (IMS). This data was used on a periodic basis to develop cost/schedule curves on microcomputers.

To meet the optimistic deadline, the project schedule was revised so that the design, procurement, construction, and installation activities overlapped to the maximum extent possible. Also, the duration of some activities, such as design approvals and bid cycle, were reduced and construction resources were increased. The project schedule was closely monitored and updated weekly for better control.

Design Schedules

To expedite the project, various project-management techniques and different project-control software were tried. However, progress curves were found to be more effective for engineering schedules (Fig. 10). The progress curves were used mostly to control engineering schedules and to determine project funding status. Due to rapid scope changes, the curves provided flexibility in updating, and because of this, they were found to be more efficient than bar charts and networks. Data for the curves was collected from drawing control logs. The engineers in authority updated these logs on a weekly basis.

Construction Schedules

Site-specific construction schedules were developed by general contractors. The schedules submitted were simple manual bar charts or narrative schedules. In some instances, computerized schedules were provided.

Funding

Incremental funding was provided by FAA based on monthly projections. Because of the long lead times, expenditures had to be tracked accurately to avoid cash-flow problems. There was a month-long project interruption due to the unavailability of funds, which delayed some punch-list items, but TSSC personnel were still able to meet the FAA goals.

The original scope of the project was completed within budget due in part to considerable cost savings in the design phase. The 35 WP towers shown in Fig. 1 were completed at a cost of about $7,000,000.

DESIGN PHASE

Since the standard tower project was a fast-track project with cost constraints, it was necessary for the program manager to prioritize and tightly control the resources and develop different project execution plans for design, procurement, and construction phases. The plan included various cost and schedule constraints to ensure effective actions. Finally, the following design methodology was implemented to complete the design packages on an expedient basis, minimizing the design effort and expediting the schedule.

Site Survey

The scope of site survey work was to identify the existing fire-safety conditions of each tower and make recommendations for improving these conditions based on *Fire Safety Guidelines*. Two TSSC design teams each composed of three members, civil/architectural, mechanical, and electrical engineers, and the FAA's project engineer, conducted the site surveys. The TSSC's team members were selected based on their design and construction expertise in fire-safety projects and on their development of good interpersonal relationships. The teams surveyed 18 towers, including at least one tower from each of the eight standard tower types, and identified existing fire-safety conditions by cataloging and marking-up a copy of available as-built drawings. The teams took photos and videotaped existing conditions in those areas that were obviously in fire-safety-code noncompliance. The teams also completed a detailed checklist and evaluated the fire-safety level of the facility. After gaining greater experience and knowledge through these visits, a cost-savings plan was implemented for the remaining seventeen sites by reducing the team to the FAA's representative and two engineers (in the case of small towers one engineer was used) who worked under the direction of design staff and obtained information as requested. Videotaping the site conditions also saved cost. These videotapes were viewed in the design office by all the engineering disciplines. The videotapes supplemented site

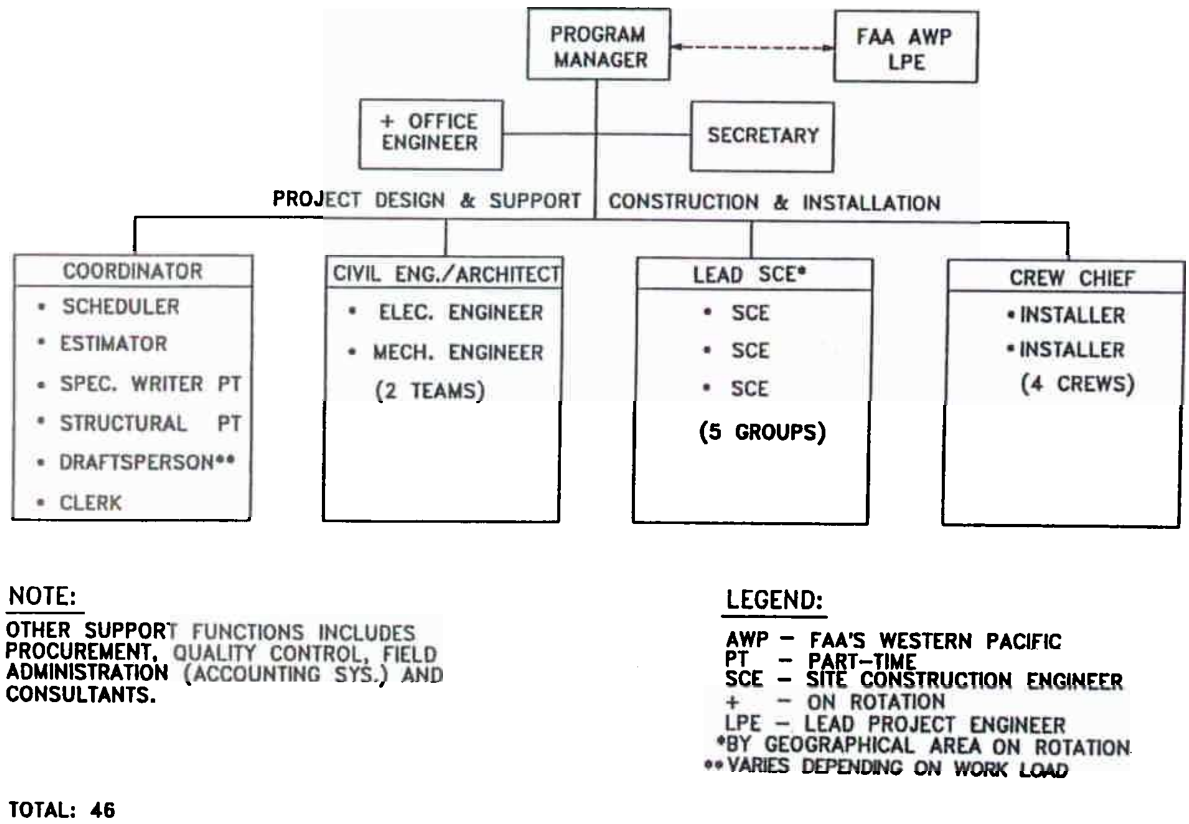

FIG. 9. TSSC—Western Pacific Region, Standard Tower Project Organization (Partial)

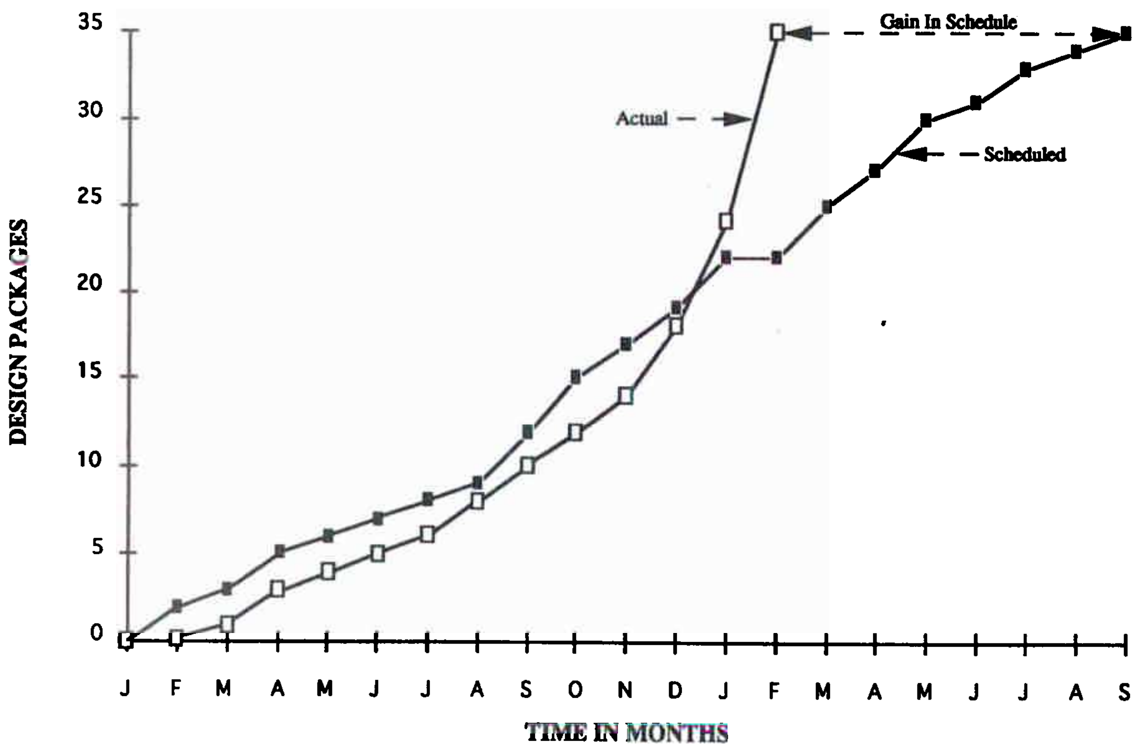

FIG. 10. Progress Curves Showing Status of Design Packages

survey report. Some towers had to be revisited for verification.

Sufficient research was done by the survey teams prior to the site surveys to expedite the work, including reviewing existing as-built drawings and discussing the issues with other discipline engineers. In the absence of as-built drawings, background drawings (or tower plans) were developed, based on the standard tower type in question. Design proposals were also developed and a kick-off meeting scheduled with the survey teams, tower and maintenance personnel, including a union representative. This was set up one week in advance of the site visit to ensure that FAA maintenance personnel were available to access the locked rooms. Documents and equipment necessary to do the site survey were carried by team members.

During the site survey, the teams discussed with the FAA field personnel their needs and concerns pertaining to up grades to facilitate a smooth completion of the construction phase. They explained the scope and importance of the upgrades to concerned FAA tower and maintenance personnel, collected information pertaining to existing conditions of the facility and equipment, obtained approvals for the contractor's staging area, temporary facilities, parking, and access to utilities. Other useful actions were verifying as-built conditions, and correcting as-built and background drawings to reflect existing conditions, including upgrades.

After the survey work was completed, the preliminary design was developed by the interdisciplinary engineering teams, based on site survey reports and videotape reviews.

Value Engineering

The design team conducted value analysis after completing the preliminary design.

> Value engineering/value analysis is the systematic effort directed at analyzing the functional requirements of systems, equipment, facilities, procedures, and supplies for the purpose of achieving the essential function at the lowest total cost, consistent with meeting needed performance, reliability, quality, maintainability, aesthetics, safety and fire resistance (Construction 1991).

In addition to interdisciplinary design engineers, the team included experienced construction engineers who addressed potential field problems. The advantages and disadvantages of different design alternatives and procedures were discussed with the FAA. As the project progressed through the construction phase, comments from site construction engineers and contractors were also incorporated to further improve the design in future packages.

Some other examples of value engineering included standardization of design and materials to minimize the design effort, expedite the schedule, and reduce the cost during the design and construction phases.

Design developed for each of the eight standard types of towers was used as a generic design and site adapted to other similar towers. Design details that were most commonly used were standardized (with minor variations) to reduce the design effort. Some examples include stair pressurization fan details, engine-generator (EG) concrete pads, and trenching details for conduits.

Materials and equipment that were commonly used were standardized by employing the same manufacturer/supplier and buying in bulk, thus reducing cost. Some examples include auto-dialers, emergency lights, door holder/closers, fans, and fire-stopping materials. Also, where possible, electrical and mechanical designing was performed with maximum reuse of existing equipment and materials. In this category were engine-generators, panels, conduits, wiring, and receptacles.

The selection of materials and equipment was based on a market survey, including comparisons of technical features and cost. Materials with lower costs but with the same performance level were recommended.

During the site survey, if the doors/frames appeared to be rated but did not have fire-rating labels, the designers recommended that they be examined by an approved laboratory and relabeled when possible rather than replaced.

Other instances of value engineering in the construction phase included using 1/2 in. Fire Code C Core or 3/4 in. Ultra Code Core with the same performance or higher in lieu of two layers of 5/8 in. Type-X gypsum board in order to reduce the cost.

Constructability Review

The constructability review of any project is vital. However, in the beginning of the standard tower project, some sites were not reviewed for constructability due to schedule constraints. According to the Construction Management Committee of ASCE (1991), "A constructability program is the application of a disciplined, systematic optimization of the construction-related aspects of a project during the planning, design, procurement, construction, test, and start-up phases by knowledgeable, experienced construction personnel who are part of a project team."

Because of the retrofit nature of the project, it was essential to do a constructability review to ensure that the designers considered all factors, including existing field conditions. Some of the aspects of the constructability review were accomplished during value engineering due to an overlapping of the functions. The goal was to produce a workable design package at a minimum cost and schedule, and at the highest possible quality.

Some recommendations of the constructability review: (1) In Hunt/Avco tower types, the fire-rated sheet rock was applied on existing walls, in lieu of removing nonrated walls; (2) Rather than replacing existing metal transom panels above the doors with new fire-rated metal panels, a fire-rated sheet rock was added; and (3) Instead of fireproof-spraying the structural members, the members were enclosed in a rated enclosure.

Detailed Design

After the FAA's determination of the scope of work, the detailed design was developed by reviewing the preliminary design and the *Fire Safety Guidelines*. The Uniform Building Code has a separate chapter on control towers (Appendix, Chapter 7); however, this section has been implemented mostly for new towers. In the standard tower project, the emphasis remained on the *Fire Safety Guidelines*.

At this time in the schedule, there were continuous interface and design review with both the regional and national FAA. In some cases, the design reviews and approvals took three to four weeks, thereby impacting the schedule. This period was later reduced to one week. Survey reports from all design disciplines, as well as discrepancies in standard abatement drawings and *Fire Safety Guidelines*, were discussed with the FAA and also with fire-protection engineers as necessary.

The FAA facilities included a wide variety of solid-state electronic equipment. To protect this equipment from electromagnetic interference and from improper grounding, bonding, and shielding practices, the FAA developed its own codes to be used for all their facilities. These codes were also used for the standard tower program. The unique FAA codes such as those for grounding and lightning protection are not common to the construction industry. In some cases they are more stringent than other national codes, such as those of the National Electrical Code (NEC) and National Fire Protection Association (NFPA).

To ensure that local interests had been duly considered, plans were also submitted to various cities and counties for their review and comments. However, due to a waiver of plan check and permit fees for federal agencies, some cities and counties either took longer review periods or did not perform the plan check. The final design package included complete computer-aided engineering graphics (CAEG) engineering drawings, specifications and a detailed cost estimate. Four towers were manually drawn in absence of as-builts. They were later converted to CAEG drawings.

In some cases, not all of the design recommendations or interpretations of the *Fire Safety Guidelines* were implemented due to difficult field conditions, design or program constraints.

Fire-Safety Upgrades

The principal architectural, mechanical and electrical upgrades are discussed later. These upgrades varied from site to site depending on existing conditions and fire-safety violations. Some of the upgrades are shown in Figs. 11 and 12. Typically, towers included office room, break room, equipment room, telephone equipment room (Telco), operations room, elevator machine room, and so forth.

Architectural Upgrades

The architectural fire-safety upgrades for items, such as stair enclosure, fire-rated wall for elevator and utility shafts, and offices, are shown in Figs. 11 and 12.

The principal objective was to protect the stairway from the adjacent areas, since the likelihood of a fire starting in the stairwell is low. The standard towers typically contain only a single exit stair; hence, it was vital to maintain a fire-protected, smoke-free exit path and a safe means of evacuation. If the exit from the cab, a workspace for air traffic controllers with glass on all sides to provide an unobstructed view from the top of the tower (see Figs. 2–8 and 12), did not open directly into the existing stair, such as going through another space, this portion of egress was separated from adjoining spaces by rated construction. Also, if the exit stairs did not discharge directly to the exterior, but passed through other spaces, then a rated separation was provided. The fire resistance membrane was installed on the fire side (Figs. 11 and 12). Where possible, a standard design assembly was used (Underwriters Laboratories or other approved laboratory).

Fig. 13 shows fire-rated conditions for a tower with a base building. Fig. 13(a) shows case No. 1: tower joined by link—1 h separation at each end of link. Fig. 13(b) shows case No. 2: tower connected directly to base building—minimum 1 h separation between tower and base building. Fig. 13(c) shows case No. 3: tower surrounded by base building—2 h separation between tower and base building.

The required fire-resistance ratings varied from 1 h to 2 h depending on existing conditions (sprinkler, standpipe system), construction type (combustible, noncombustible) and height of the tower.

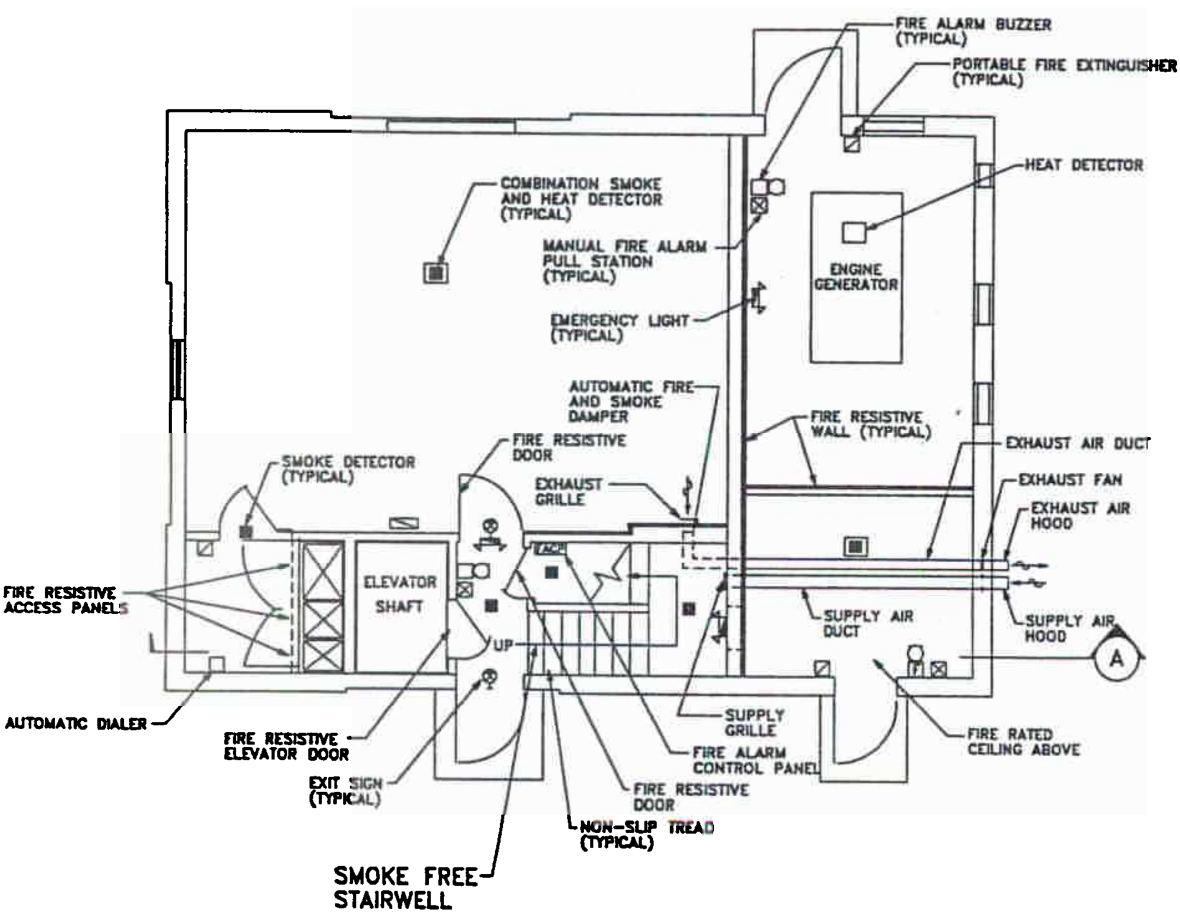

FIG. 11. Tower Plan

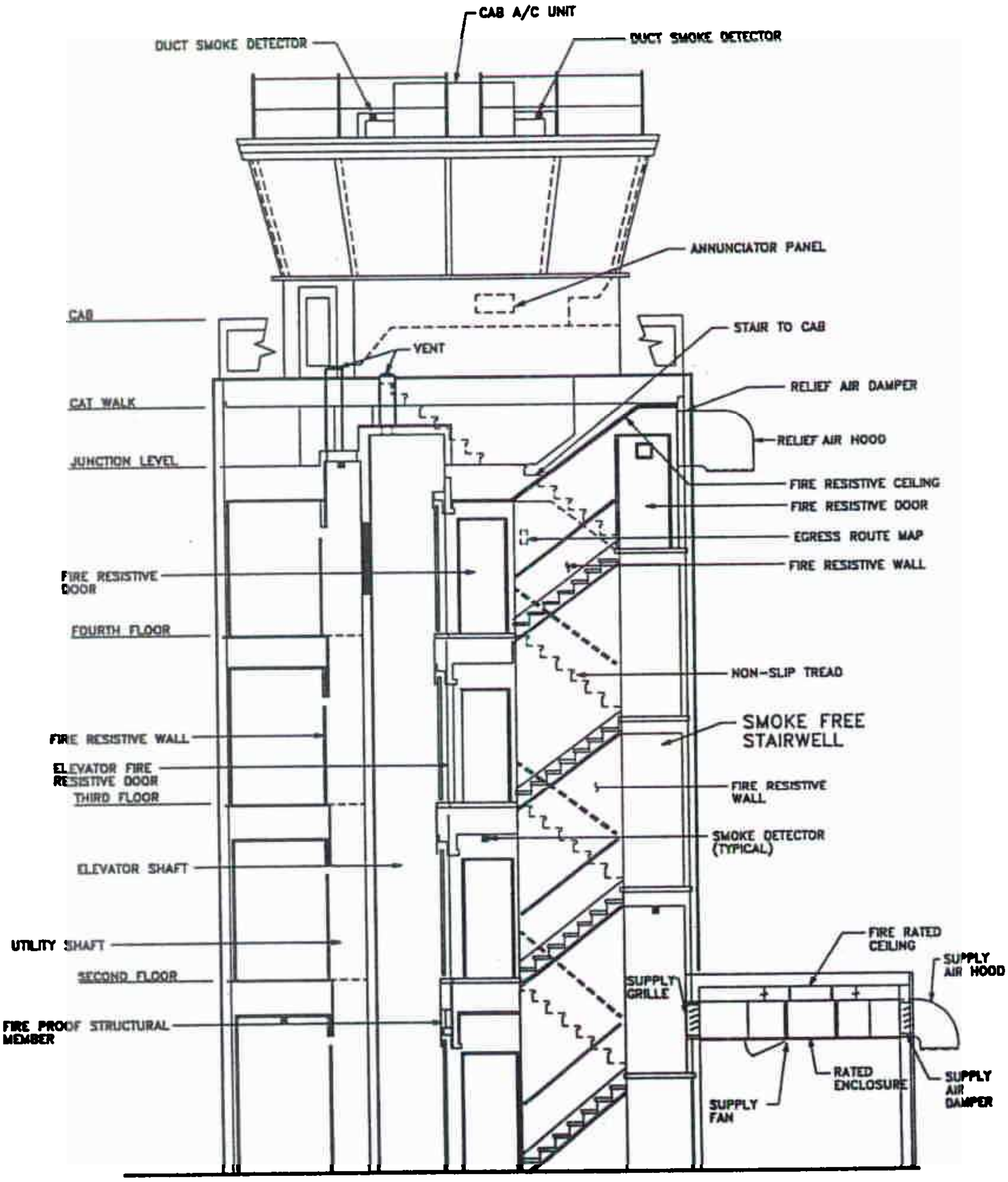

FIG. 12. Tower Section A

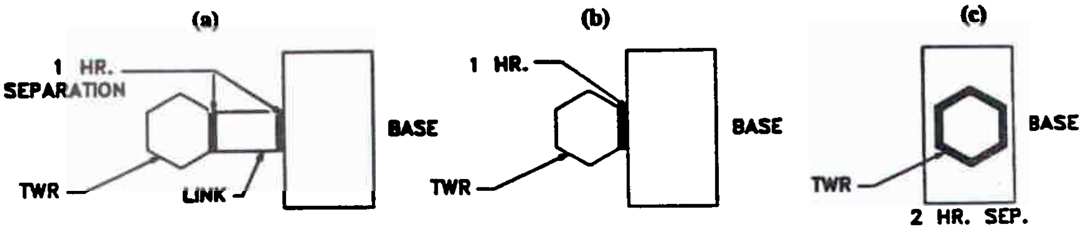

FIG. 13. Fire-Rated Conditions for Tower with Base Building

Mechanical Upgrades

The mechanical fire-safety upgrades such as installation of pressurization fan and dampers are shown in Figs. 11 and 12.

Studies have shown that smoke causes more fatalities than fire. Two arrangements for smoke management systems were used, which follow.

First, for a smokeproof enclosure, a ventilated vestibule was provided at the stair entry of each floor to intercept smoke moving to exit stairs and to exhaust it to the outside. The exit stair is maintained at a pressure of 1.27 mm (0.05 in.) of water column relative to atmosphere, and a minimum flow of 1,180 L/s (2500 cfm). The vestibule was upgraded with fire resistive materials, depending on existing conditions and type of construction.

The second system is the common method used in the U.S. for smoke management, the stair pressurization system, which has been provided in the absence of a vestibule, and which minimizes smoke entry into the stairway. The system includes a supply fan and damper, and a relief damper. Figs. 14 and 15 show mechanical and electrical schematics for stair pressurization systems. They activate on receipt of a signal from the fire-alarm control panel and are operated on either normal power supply or an emergency supply system. Each system maintains an acceptable positive pressure of at least 3.81 mm (0.15 in.) of water column, and no more than 8.89 mm (0.35 in.) of water column relative to the building. There were many variables for the design of the pressurization systems in these retrofit projects. These included leakage of air through cracks, openings and doors; temperature differential (interior and exterior), height and configuration of the tower, wind velocity and direction, and the losses occurring due to occupants opening the doors during fire evacuation.

The most important factor is that the pressurization system must have sufficient pressure to prevent smoke from entering egress stairs. At the same time, there should not be excessive pressure that would make it difficult for the occupants to open doors. According to *Fire Safety Guidelines*, the design of the pressurization system must be done with all doors closed. However, in some taller towers, the design criteria were more stringent and the design of pressurization system was done based on one door leading to egress path open. This led to a larger fan size. Each pressurization fan is interlocked with the tower fire alarm system and is activated by a signal from the fire-alarm control panel. An adjustable time delay relay is provided with the fan starter to delay the fan operation and to allow the dampers to open before the fan starts up.

Electrical Upgrades

The electrical fire-safety upgrades such as fire-alarm systems, each of which includes a fire-alarm control panel, one or more annunciator panels, an auto dialer, and associated devices, are shown in the Figs. 11 and 12. To avoid distraction in the tower cab where the controllers monitor the air traffic, a special silencer switch was installed in the annunciator panel to silence the audible alarm. However, the alarms remain active in the rest of the facility and the flashing red lights remain on in the annunciator panel.

Generally, the emergency power supply system is provided in towers mainly for operations of air-traffic-control equipment. In some cases, there are existing engine generators and battery backup systems with enough capacity to operate fire alarms and stair pressurization systems. During design upgrade for the standard towers, it was found that 17 towers needed engine generators. For these towers, it was decided to install standby propane engine generators with 7 kW (6.01 Kg-cal/hr) and 10 kW (8.59 Kg-cal/hr) capacities, along with associated equipment, such as automatic transfer switch (ATS), bypass isolation switch, and other equipment.

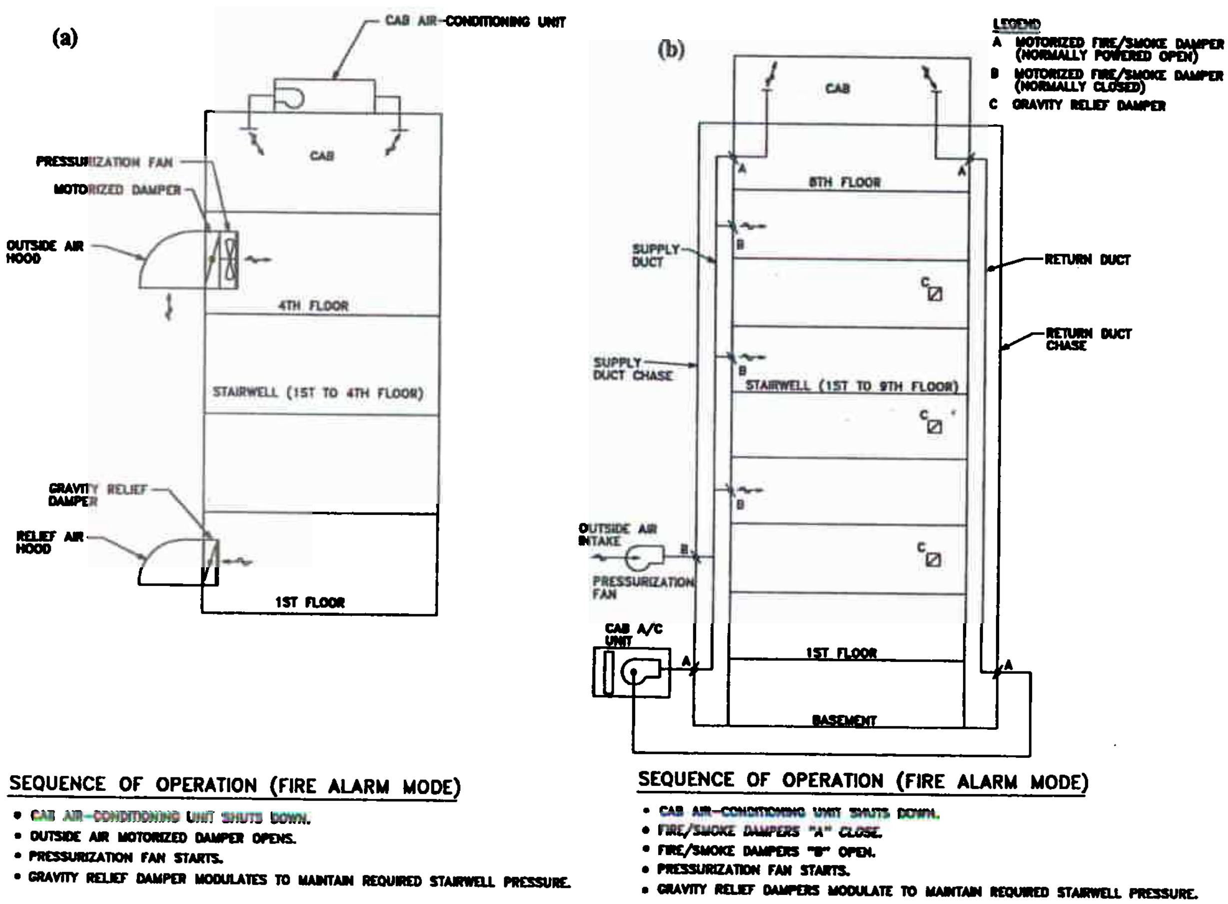

FIG. 14. Stair Pressurization System (a) Towers up to 26 m (85 ft); (b) Towers Higher than 26 m (85 ft)

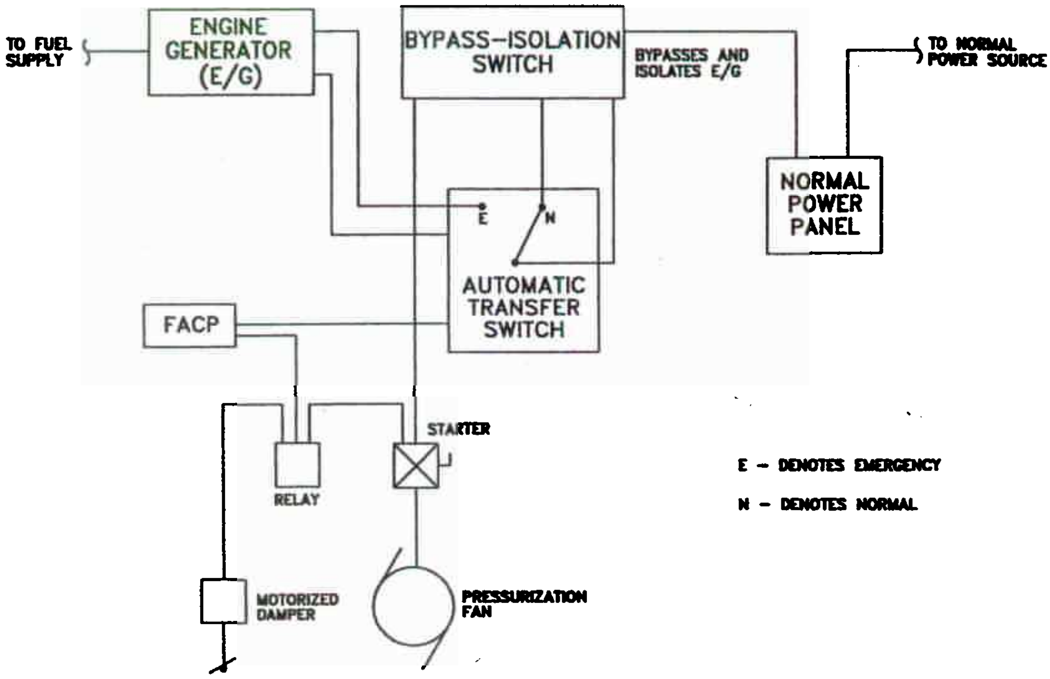

FIG. 15. Stair Pressurization System Electrical Control

PROCUREMENT PHASE

TSSC construction contracts were each awarded to a general contractor who then subcontracted various portions of the work to other specialized contractors by trade. All construction contracts had a fixed price and were awarded to the lowest bidder on a competitive basis. The goal was to award 50% of construction contracts to small disadvantaged businesses (SDB). This goal was achieved.

CONSTRUCTION PHASE

Construction work involved supervision of the general contractor's work by the TSSC site construction engineer (SCE). The SCE worked under the direction and support of the head office for both technical and contractual requirements. The SCE was required to maintain several field documents for design implementation and to ensure continuous communication. The SCE was provided with a construction handbook, which included forms for weekly progress reports, labor standard interviews, test reports, submittal logs, periodic estimates, clarification notices, noncompliance notices, change orders, stop orders (in emergency), accident reports, punch lists, contractor's acceptance inspections (CAIs), and project closeout papers. In addition, the SCE maintained a daily construction diary, red-lined drawings, and certified the contractor's payroll.

Regular inspections were conducted by the program manager, the quality control inspector, and the FAA to ensure that the contract documents were in accordance.

MAJOR CHALLENGES

During the upgrades of standard towers, design discrepancies and construction difficulties were encountered and resolved. The following points summary some of the major difficulties encountered.

Problem: The general scope of the work for the Hunt/Avco type towers was increased 12% without a corresponding increase in the project completion date. Additional work included the installation of fire-rated walls at junction levels, strengthening the floors by adding structural members to distribute the new equipment loads, relocating the electronic communication equipment and associated utilities from the junction level floor and reinstalling it on another floor without any disruption to the tower operations (Fig. 16).

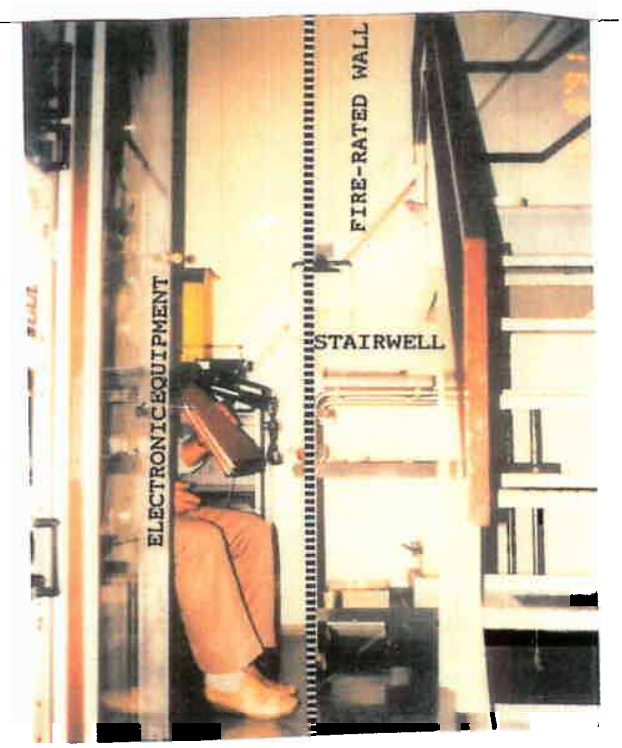

FIG. 16. Fire-Rated Wall Installed to Separate Stairwell and Electronic Equipment (Hunt-Avco)

Resolution: The site-specific scope was developed as the project progressed on an as-needed basis. The program manager increased the resources and emphasized in-house engineering and installation for better control.

Problem: The scope of the work was increased 5% by adding 5kW and 10kW engine generators for the stair pressurization system since existing engine-generators did not have enough capacity. In some cases, the EGs were not delivered on time, and resulted in a delaying impact on pressurization testing and acceptance.

Resolution: Change orders were issued and the contractors were instructed to complete all of the associated work, such as the conduits, wires, and concrete pad, and to return and install the EG at a later date. In some cases, a separate contract was negotiated to do this work. Where the EGs were installed under such a separate contract, close coordination was done with the contractors who had previously installed the pressurization system, to facilitate smooth testing and acceptance. A contingency plan was developed for renting or leasing EGs, in case the EGs were not delivered.

Problem: The selection of EG locations was time consuming. In some instances, the location had to be changed after the start of construction.

Resolution: The FAA expedited the real-estate–acquisition process.

Problem: In some cases, the available as-built drawings of the equipment did not show all of the existing cables and their connections.

Resolution: The installers had to work during the night shift (when the towers were closed) to test the cables for identification.

Problem: The existing fire-alarm system and panels were many years old. Adding new devices, replacing parts and retesting was not easy.

Resolution: In some cases, a new fire-alarm system was installed. Where the existing system was modified, the original system manufacturers and installers were contracted to do the modifications. The WP region was unable to replace new fire alarm systems in all of the towers due to cost constraints. However, the systems were upgraded if not replaced.

Problem: It was not possible to schedule contractors along with electronic crews at the same time, due to confined space. In some instances, the equipment was relocated twice.

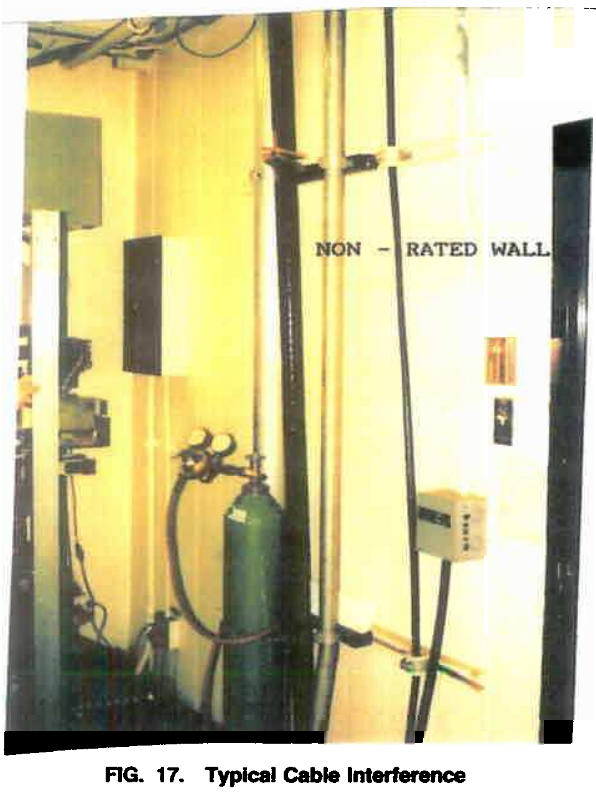

FIG. 17. Typical Cable Interference

Resolution: The program manager instructed the contractors and installers to work in different shifts but with close coordination.

Problem: Installing the fire-rated gypsum board in cable chase and elevator walls was difficult because of tight working spaces.

Resolution: In some towers, the contractor had to remove the existing metal walls to install the fire-rated cable chase walls. To obtain proper clearance between the elevator cabs and walls, minimum thickness of gypsum board with required performance was used in elevator shaft walls.

Problem: Installation of fire-rated gypsum board on top of existing nonrated walls was difficult due to electrical panels and cables attached to the walls (Fig. 17).

Resolution: Before installing the new fire-rated wall, the equipment and utilities were unbolted. Temporary supports were provided by the contractor to panels and cables attached to the walls. The equipment and utilities were then reinstalled on the wall.

Problem: In some towers, fire-rated swing doors and frames of existing elevators could not be installed because of physical constraints. The reason for installing swing doors was to provide a proper separation between stairwells and elevator shafts when elevator door was open.

Resolution: In lieu of deleting the swing doors, the size of the pressurization fan, as well as ducting sizes, was increased to compensate for air leakage through gaps around an elevator sliding door. This door stays open during fire alarms.

Problem: The difficulty in procurement of long-lead-time materials for electronic equipment, such as cable trays and specialized tools caused a problem. In addition, material availability and delivery problems existed at Hawaiian sites.

Resolution: The crew worked on other installation activities that did not involve long-lead-time materials, and returned to install the long-lead-time materials at a later date. At the sites with material availability problems, the contractors were instructed to use substitute materials with the same performance. The delivery problems were resolved by air freighting the materials.

Problem: In some cases, the bid cycle for construction contracts exceeded 5 months.

Resolution: The bid cycle duration was reduced to 3 months to expedite the schedule.

Problem: In some cases, the contractor's performance was not expeditious.

Resolution: Stricter compliance to the schedule was enforced, and in some cases, actual damages were assessed.

Problem: In the beginning, the approval of field change orders took more than a week.

Resolution: The approval time was reduced to 1–2 days by obtaining verbal approvals, followed later by the paperwork. The change order forms were also amended, reducing the number of signature authorities.

Some of these problems were bound to exist in a retrofit project. However, many difficulties could have been avoided by providing adequate funding and making an earlier determination of the project's scope.

RECOMMENDATIONS FOR FUTURE PROJECTS

On subsequent projects, it is suggested that:

- Full identification of the scope of the work be made prior to start of the project.
- The project be fully funded.
- An effective project management system be implemented

by integrating cost, schedule, and performance measurement systems.

- All new towers be constructed in strict compliance with OSHA, fire safety requirements, and other national and local codes and regulations.
- Computer-generated maintenance and testing schedules be kept of fire-safety equipment.
- Site-specific detailed drawings be developed rather than using generic drawings that are site-adapted.
- Schedule durations be increased for site surveys, constructability, permits, and government regulations.
- As-built drawings be continuously updated to current conditions.
- Realistic construction schedules be developed. Construction schedules should not be compressed if the planning or design schedule falls behind.
- Real-estate acquisition process be started earlier in the project.
- Contractors procure all the materials and equipment prior to the start of the work. In case of long-lead-time items, orders must be placed immediately after approval of the submittals.
- Owner-furnished materials be considered for long-lead-time items.
- The Bid cycle duration for construction contracts be based on value, complexity, and geographical location of the project.
- Requirements for qualifications of the contractors and contract management be stringently enforced. Include liquidated damages and incentive clauses in contract documents. The incentive clause should also include cost sharing for adopting contractor's cost improvements methods.
- A database of "lessons learned" be developed and maintained.

CONCLUSIONS

The major objectives of the OSHA upgrade project were met in all 35 standard towers. Each tower was modified to include a smoke-free, fire-protected means of egress and an early-warning fire detection and alarm system, as specified by *Fire Safety Guidelines*. Installation of these fire-safety upgrades, as well as additional safeguards to limit the spread of fire and smoke, was completed on time and within budget. Major problems with engine generators, equipment relocation, junction wall installation, the pressurization system, materials procurement, etc., were overcome by effective project management.

The safety of the FAA's work spaces is a major priority, not only in the region's air traffic control towers, but also in all facilities containing their most important resource: the men and women who maintain and operate the National Airspace System. The success of the project in meeting the major objectives may be exemplified someday in the safe evacuation of a facility during the threat of fire or other emergency situation.

APPENDIX. REFERENCES

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