

CONSTRUCTABILITY CONCEPTS FILE

TABLE OF CONTENTS

<i>Section</i>	<i>Page</i>
Introduction	1
I. Constructability Concepts During Conceptual Planning	5
Concept I-1: Constructability programs are made an integral part of project execution plans.	5
Concept I-2: Project planning actively involves construction knowledge and experience.	13
Concept I-3: Early construction involvement is considered in development of contracting strategy.	17
Concept I-4: Overall project schedules are construction sensitive.	21
Concept I-5: Basic design approaches consider major construction methods.	25
Concept I-6: Site layouts promote efficient construction.	29
II. Constructability Concepts During Design and Procurement	35
Concept II-1: Design and procurement schedules are construction sensitive.	35
Concept II-2: Designs are configured to enable efficient construction.	45
Concept II-3: Design elements are standardized.	53
Concept II-4: Construction efficiency is considered in specification development.	57
Concept II-5: Module/preassembly designs are prepared to facilitate fabrication, transport, and installation.	67
Concept II-6: Designs promote construction accessibility of personnel, material, and equipment.	79
Concept II-7: Designs facilitate construction under adverse weather conditions.	85
III. Constructability Concepts During Field Operations	

INTRODUCTION

This publication is based on the experience of the owners and contractors represented on the CII Constructability Task Force and on the findings of research programs directed by the task force. The research convincingly shows that major cost savings and schedule improvement can result from the effective implementation of the principles of constructability. The task force defines constructability as "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives."

Thirteen constructability concepts are presented in this report, along with sample applications of the concepts. The first six concepts relate to the conceptual planning phase of a project. The remaining seven relate to the design and procurement phase. Concepts relating to field operations will be distributed at a later time.

Collectively, the concepts and their applications present representative good practices in a manner that will enable practitioners in any organization to take advantage of the lessons learned by others and apply them in their organizations and on their projects. While the reader may find that some of the concepts or applications will be directly applicable to their projects, the primary purpose of the *Concepts File* is to stimulate thinking about constructability and how to make it work. This is not a checklist, nor is it a cook book. Experienced people will have to study the concepts and the sample applications to determine which will be best for their company and their projects.

Conceptual planning involves defining functional and performance requirements, evaluating project feasibility, and studying criteria for preliminary engineering. The decisions made during this phase have a major impact during the remainder of the project, particularly on construction. The concepts concerning the benefits of construction involvement in project planning, development of the contracting strategy, and selecting major construction methods that influence the design approach clearly indicate the need to involve those who will build the project as it is being defined.

Design and procurement is the phase in which most serious practitioners of constructability have previously addressed their efforts. In comparison to the preceding phase of conceptual planning, the cost impact of decisions here is still very high and many opportunities exist for enhancing constructability. The nature of these improvements, however, can be quite different. While conceptual planning constructability tends to focus on project objectives, organization, and execution plans, design/procurement constructability is manifested in the form of drawings, specifications, purchase orders, and schedules.

The task force research also identified the best practices in organizing for constructability among many companies. These practices are presented in *Guidelines for Implementing a Constructability Program*, which will help the reader begin the development of his own company specific programs. It will also be helpful in thinking through the nature of the constructability efforts that may be appropriate for a given company in the formulation of a policy statement, in the development of the

constructability organization, and in the establishment of the basic procedures to be followed.

The task force believes that the adoption of new technology such as three-dimensional computer aided design/drafting (CADD), robotics, and automation in construction will have a revolutionary impact on construction methods and techniques. Constructability personnel must be prepared to adapt to these new approaches and provide the appropriate planning input to all the participants who will impact directly and indirectly on the construction process. This publication is designed to assist in the dynamics of that important process.

The initial publication by the task force, *Constructability: A Primer*, and its second publication, *Guidelines For Implementing A Constructability Program*, are included with this notebook. Future research results on constructability will be forwarded by CII as additions to the notebook.

I

CONSTRUCTABILITY CONCEPTS DURING CONCEPTUAL PLANNING

Concept I-1: Constructability programs are made an integral part of project execution plans.

Discussion

This concept establishes the position that if constructability is to be achieved on a project, the plan for achieving it must be published as part of the project execution plan. A project execution plan is an integrated and coordinated program for completing all project activities and achieving all project objectives. In most cases these plans are prepared by an owner project manager at a very early stage of the owner's project efforts. These owner plans then influence the nature of the plans of the designers and constructors, which will be coordinated with the owner's plan. In the absence of an owner plan, designers and constructors each benefit from having their own project execution plans governing their scope of work.

An execution plan is comprehensive, covering the project organization and its operating procedures, the schedule and budget, and the overall project strategy. It also

includes the contracting/subcontracting plan, the procurement plan, and the construction plan. It defines the project environment and identifies potential constraints to the successful completion of the project. Project execution plans are prepared in different ways by owners, designers, and constructors with varying degrees of formality according to the nature and size of the project. The areas listed above are considered, however, in all project execution plans - explicitly or implicitly. When a project manager wants a high level of confidence that a functional area such as constructability will be addressed effectively on a project, a written plan will be published for that area as an explicit part of the overall execution plan.

Implementing constructability may mean implementing change in many organizations. It will not happen unless the change is well planned and well managed. While a corporate program is important to assure consistency in approach on all projects, project-specific programs really make it happen. If a project-specific constructability program is not totally integrated into the project execution plan, constructability will not be achieved. If constructability is viewed as a special effort, not a regular part of project planning, design, and construction, then its full benefits will not be achieved. Constructability will not be achieved by a group of specialists trying to influence project activities from the outside. They must be a part of the project team and work on the inside of the project. This can only be achieved when the organization and procedures of doing so are set forth in a constructability program that is published by the project manager as an integral part of the project execution plan.

A project-specific constructability program applies the general constructability policies, organizational philosophy, and procedures of a company to the specific conditions of a project. The purpose of the program is to make optimum use of construction knowledge and experience to meet project objectives. The program should build a team approach of "thinking of the effect on construction of all project decisions" in making major decisions during all phases of a project, especially during conceptual planning and preliminary engineering. These programs do not optimize construction at the expense of other activities, but rather encourage decision-making based on the needs of the entire project.

Constructability programs contribute to effective project execution in many ways, including:

Helping to establish project goals and objectives. Goals of the engineering and construction groups should support overall project goals, thus avoiding the pitfall of sub-optimization.

Providing a logical and systematic manner for integrating design and construction. The concept of constructability is as old as the engineering, design, and construction process - it is nothing new. The problem lies in getting people (designers and constructors) from diverse cultural backgrounds and with potentially different driving goals to work together effectively. A constructability program can provide the mechanism for effectively integrating design and construction - a "common sense" need that has been recognized for a long time.

Providing a mechanism for obtaining field construction expertise as needed. Problems or alternatives involving methods/techniques, materials, equipment, etc. can be resolved before design is finalized in a manner that reduces field costs without adversely impacting design cost/schedule. Better yet, a constructability program can be useful in the development of project specifications, thus getting construction knowledge into the design effort at a very early stage.

Improving the understanding of design intent by construction personnel. This shared understanding increases mutual respect, aids communication, and can prevent construction from making a serious mistake from a seemingly insignificant field change.

Implementation of this concept will vary among owners, designers, and constructors, and from one contracting approach to another. Regardless, it is important that a plan be established to achieve constructability in all phases of a project by all participants within the parameters of the overall project execution plan and the execution plans for the separate phases.

Applications

Owner Constructability Programs. When an owner decides to proceed with a capital project, a project execution plan to achieve the project objectives should be prepared early in the project development effort. This plan defines how the necessary resources will be brought to bear on the project, including in-house staff and contractor capabilities to accomplish design and construction. A constructability program should be a part of the

owner's execution plan to establish how the owner will acquire and utilize construction knowledge and experience during the early conceptual planning phase of the project, and to define what the owner will require contractors to do to achieve constructability for their respective areas of effort.

Design-Build Contractor. Where an owner assigns both design and construction responsibility to a single firm, the contract should include a requirement for the contractor to incorporate constructability into his execution plan. This provision is appropriate under either a fixed-price or a cost-reimbursable contract. In either case, the owner can set forth his minimum requirement and establish his right of approval.

Construction Management Contractor. Owners may employ a construction management contractor to act for the owner in planning and achieving the project objectives. The contract should establish the nature of the constructability program required of the construction manager. The owner also can require the construction manager to include a constructability program in other design and construction contracts, all of which should be coordinated so that the set of execution plans effectively address all actions required by all parties in executing the plan. In the absence of an owner plan or a requirement by the owner for the construction manager to prepare an execution plan, independent action by the construction manager will be beneficial in achieving an effective constructability program.

Design Contractor. Designers prepare their own project execution plans, which reflect their contractual commitments to owners and their own company approach to

planning and executing their work. These plans are coordinated with owner execution plans. Designers should include constructability in their execution plans. These plans will reflect owner constructability requirements. If the owner has not established a constructability requirement, the designer should establish his own constructability program to improve the quality of his design products. The designer's program should identify the source of construction knowledge and experience to be employed on each project. This will be crucial in establishing the credibility of the designer's constructability efforts.

Construction Contractor. Construction contractors prepare execution plans for their projects. For cost-reimbursable contracts, these plans reflect the requirements of the owner in detail and are coordinated with the owner's plan. One of the advantages of the cost-reimbursable contracting approach is that it permits bringing the construction contractor on board early. This enhances the effectiveness of the constructability program. If an owner does not prepare an execution plan or does not require the contractor to prepare a constructability program, contractors can prepare constructability programs as a part of their execution plans and present them to the owners for their concurrence in the reimbursable expenses involved. Under fixed-price contracts, the construction contractor should be motivated to develop an effective constructability program for construction activities to enhance his competitive position. The constructability program should be published as a part of the contractor's overall execution plan.

Major Vendors of Sub-Units or Systems. Owners, designers, and construction contractors should require major vendors of sub-units or systems to consider

constructability in the design, fabrication, and shipping of their products, whether shipped as components or preassemblies. This can be accomplished by including specific requirements in requisitions and purchase orders. Examples are water treatment plants, steam generating units, prefabricated buildings, and packaged heating and cooling systems.

Constructability issues involve:

- a. Compatibility of specifications contained in or referenced by the procurement document with field construction specifications.
- b. Obtaining advanced information on the degree of completeness, i.e., is the unit complete or unassembled; is calibration and testing complete.
- c. Obtaining vendor data and certified drawings relating to construction in a timely manner. The key is the proper and detailed identification of the data in procurement documents.
- d. Logistical considerations, i.e., method of shipment, offloading and storage requirements, special lifting or handling considerations.
- e. The site need date should be specified in purchase orders to avoid delays and costly work-around solutions.

Concept I-2: Project planning actively involves construction knowledge and experience.

Discussion

This constructability concept addresses achieving cost and schedule benefits through the inclusion of construction people in the early planning teams. When faced with a decision to construct a new facility, owners establish formal or informal project planning teams. These teams are responsible for determining how best to satisfy a business need, for example the manufacturing of a new product, increasing existing capacity, reducing costs, or improving quality. Many factors are involved in these analyses with most being obvious, including:

- * Availability of raw materials
- * Availability of skilled labor
- * Cost of labor
- * Costs of transportation of raw materials and finished products to market
- * Plant capacity
- * Manufacturing process
- * Potential for plant expansion

Often these planning teams do not include members with significant construction knowledge and experience. A number of construction sensitive factors can influence the cost and time frame for completion of construction, and these can be acted upon during the conceptual planning stage of a project when the potential for influence is greatest if people

who are sensitive to them participate in the planning process. It is critical that the right kind of construction people be on the team at the beginning of a project.

Applications

Establishment of Project Objectives. One of the early efforts by the planning team is establishing the overall project objectives. These objectives should address the balance among such areas as cost, schedule, quality, and reliability. Clearly stated objectives and relative priorities will be useful in development of project design criteria, specifications, and the quality assurance program. These objectives also will be important in preparing the project execution plan, including the budget and schedule. The participation of an experienced construction person on the team will insure that all implications to construction operations will be considered. The implications are not always apparent to people without field construction experience. Highly competent executives and engineers sometimes are not familiar with construction related issues that may have major cost and schedule saving potential. It is important that these issues receive consideration during early project planning.

Selecting Major Construction Methods. Early construction planning is necessary to select major construction methods, and to assure that the design approach is both consistent and supports these methods. Modularization and prefabrication/preassembly must be considered during the early project planning. Such considerations are important when selecting major construction methods.

Site Selection. While business factors normally influence the general geographic area for a new facility, the choice of a specific site in this area can in many cases impact construction productivity, cost, and schedule. For example, subsurface conditions normally are explored by geotechnical consultants, but only infrequently are site logistics issues such as access for heavy equipment, laydown areas for temporary storage, and local transportation of the labor forces adequately examined. Experienced construction people understand the importance of these and similar issues.

Schedule Feasibility. Most projects are driven by market forces, and are considered economical when they deliver a product or other value at the right time. This translates into an overall project schedule that involves planning, design, procurement, and construction. The schedule implicitly involves many assumptions and risks. A major risk factor is the overall duration allowed for construction. Knowledgeable construction people can minimize the risks and provide experienced input to schedule feasibility.

Productivity Assumptions. During early project planning, field labor productivity assumptions must be made when developing project economic feasibility estimates. A construction person, particularly one who has previous experience in the region, is well qualified to prepare these estimates. The availability of skilled labor within commuting distance, the need for training programs for specific crafts, the need for a construction workers camp, and the impact of adverse weather are all important considerations for productivity during the project. If these are not accurately assessed during early project planning, later changes in costs are inevitable.

Preparing Estimates and Budgets. Construction input is essential in preparing estimates and budgets for the project. Without specific construction knowledge supported by site surveys, there is a tendency to apply general company experience from seemingly similar past projects without recognizing the differences of the current one. Specific estimating assumptions regarding major construction methods, productivity of craft labor, indirect costs, and the unique conditions of the site can be effectively made by a construction person.

Developing the Contracting Strategy. Construction input can be helpful in evaluating the alternative contracting strategies available to an owner and in the selection of the strategy that best suits the project's needs. This will involve assessment and allocation of risk, consideration of the urgency of the schedule, the degree of flexibility that may be required during the project, and the objectives concerning project cost.

Sources of Commodity Materials and Engineered Equipment. While the selection of vendors is primarily a project procurement responsibility, an experienced constructor can provide valuable input to the owner, designer, and procurement agent concerning past experience with specific sources, the need for in-plant quality surveillance, and the need for special purchase order provisions to optimize the delivery of items as specified, on time, and in the sequence required.

Concept I-3: The source and qualifications of personnel with construction knowledge and experience varies with different contracting strategies.

Discussion

This concept addresses how owners can obtain the assistance of experienced construction personnel under different contracting strategies. In the preparation of project execution plans, owners develop their contracting strategy. This is governed by the owner's basic philosophies concerning cost-reimbursable, fixed-price, and other commercial arrangements, and whether the owner prefers to concentrate responsibilities through design-construct contracts or divide responsibilities through separate design and construction contractors. A variety of strategies are available. The specific strategy for a given project will be determined by the specific conditions and objectives of the project.

The contracting strategy will have a major influence on the availability of qualified construction personnel to serve on constructability teams. The importance of early construction input during conceptual planning has been addressed previously and cannot be overemphasized. Owners must be particularly cognizant of this situation or the benefits from constructability input will be lost. For instance, if the project delivery system employs the traditional concept of separate contracts for the designer and general contractor, the owner will have primary responsibility for coordinating early constructability input. Since award of the general contract depends upon design completion, special arrangements are required to obtain knowledgeable construction personnel during conceptual and early design phases.

Some owners have in-house construction knowledge and experience, but many will need to acquire this capability during the conceptual planning phase by some contractual arrangement. This is possible through any contracting strategy if the need is recognized early and specifically included in the strategy. Under any approach the right kind of construction people must be involved and their qualifications must be clearly specified in the contract documents. Personal qualifications are important, not just availability. Care must be taken to avoid having someone who may be available between other assignments simply plugged into the planning team in order to fill the constructability position. The right kind of construction person will be mature and experienced, and command respect from other team members. He should be a broad-gauged person who is able to understand the full scope of project activities and their interrelationships. He should not be a zealot who is concerned exclusively with construction needs. He must be able to work with people from other disciplines and be able to communicate effectively. The need for the right kind of construction people for early planning teams should be recognized, even if finding people with these qualifications may be difficult.

Applications

Using Owner Construction Staff. While this concept addresses obtaining people with construction knowledge and experience by contract, some owners maintain their own construction staff that can develop and implement constructability programs without help from other sources. Owners should be certain that their own staffs have the right qualifications for constructability before relying on them exclusively.

Using a Design-Construct Contractor. Construction knowledge and experience can be obtained if the selection of a design-construct contractor is made early enough to assist the owner during conceptual planning.

Using the Construction Contractor. An owner can select the construction contractor early to provide constructability input during project planning.

Using a Construction Contractor as a Consultant. An owner can employ a construction contractor as a constructability consultant during the conceptual planning phase of a project with no commitment to using that contractor as the ultimate constructor.

Using a Construction Manager. An owner may elect to utilize a construction manager. In this case, the construction manager's scope of work should clearly state his constructability responsibilities of the construction manager.

Using the Design Contractor. An owner may select the design contractor early enough to provide constructability services, but this approach requires great care to assure that qualified people are available. In this case, the contract with the designer should specify that the constructability advisor to the owner will be a member of the owner's planning team, not a member of the designer's design team.

Using a Constructability Consultant. An owner may use a constructability consultant who is independent of the designer or constructor. This has the advantage of not requiring an early selection of either the designer or constructor.

In all of the above cases, care is required to assure the qualifications of the people provided.

Concept I-4: Overall project schedules are construction sensitive.

Discussion

This concept establishes the principle that the project completion date and the requirements of the construction phase should be considered in optimizing the project cost and schedule. This concept addresses the overall project schedule, which balances and allocates durations of time among the major project activities. A design and procurement concept, "Design and procurement schedules are construction sensitive," addresses the detailed sequencing of effort for these activities within their allocated durations. The conceptual planning phase of a project establishes an overall project schedule by optimizing time and costs to meet the owner's required date. While design, procurement, and construction each has its own optimum sequence and duration, few overall project schedules allow the optimization of all of them. Compromises are necessary and should be made to the benefit of the overall project schedule and cost.

The planning process often uses the "forward pass" schedule technique: satisfying planning, design, and procurement time frames first, then leaving the balance to construction. This occurs because the owner and designer representatives generally are involved in the conceptual phase of a project and often tend to protect their respective activities without sensitivity to construction needs. Owners and designers frequently assume that construction has the flexibility to finish the field work in the remaining time. To achieve the benefits of constructability, owners should guard against this approach and require overall project schedules to be determined using a "backward pass" basis with an

analysis of the balance required among the times allocated to planning, design, procurement, and construction.

Considering construction early in the development of the overall project schedules has the potential of trading more costly field work for less costly planning, design, and procurement activities. The result is a cost-effective overall project schedule. If the cost of land and major engineered material and equipment items is set aside, field construction activities result in about 40 percent of the project cost. There are many more construction work-hours on a project than design and procurement work-hours. In addition, construction work-hours are expended in an environment (weather, space limitation, remoteness, etc.) less controllable than design and procurement. A construction sensitive schedule will consider these factors.

A construction sensitive schedule emphasizes the importance of the timeliness of conceptual planning. Insufficient or ineffective planning can severely impact costs during construction. Construction knowledge and experience as well as design and procurement expertise must be involved in the conceptual planning effort to establish a balanced overall project schedule. This involvement will best facilitate the allocation of the total time available to the project among all of its activities.

The following items are important conceptual planning considerations in developing construction-sensitive schedules:

- 0 The sequence of major construction activities and subcontracts.

- 0 Establishment of realistic durations for construction activity to prevent costly overtime, acceleration or counter-productive high levels of craft labor.
- 0 The effect of leveling construction resources on the accomplishment of design and procurement tasks.
- 0 The impact of weather on construction activities including the definition of construction seasons when necessary.
- 0 The lead times for delivery of major items of equipment under different procurement approaches.
- 0 The allocation of sufficient time for mobilization in remote areas including the time for recruiting and training craft labor when required.
- 0 The allocation of sufficient time for the contracting and subcontracting process.

In summary, to achieve the full benefit of constructability requires a balanced allocation of overall project schedule time. Owners and planners must be sensitive to developing construction-driven schedules during the conceptual planning phase of a project.

Applications

1. Construction input should be continuous during the conceptual planning process, not ad hoc to simply review the judgements formed by others. Construction should address the several areas set forth as applications under Concept I-2, "Project planning actively involves construction knowledge and experience."
2. Design/construct contractors should consider this concept in the development of their overall design, procurement, and construction schedules.
3. In cost-reimbursable projects with separate designers and constructors, designers should consider constructors' needs in preparing their design/procurement plans and schedules.
4. When designs are prepared for single projects for which construction will be competitively bid, owners must assure a proper balance among all project activities, including their own planning phases, design, the contracting process, and construction.

Concept I-5: Basic design approaches consider major construction methods.

Discussion

This concept establishes the principle that major construction methods must be considered during conceptual planning. These methods have significant influence on both conceptual planning and design. Their consideration during conceptual planning, a brief window of opportunity (as illustrated in Figure 1), raises cost effectiveness, design, and construction performance and improves owner value.

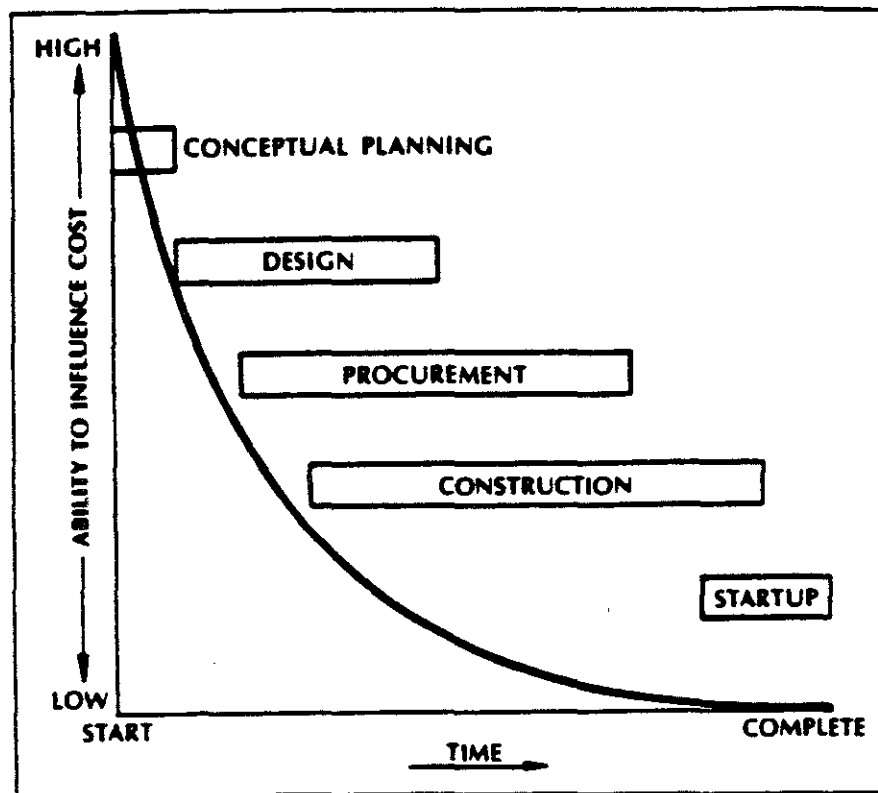


Figure 1. Ability to Influence Final Cost Over Project Life

Major construction methods can be defined as the use of construction equipment, labor, and work sequencing in such a way that the methods become a major design "driver." In this case, a design driver is a construction method, condition, or technique that design engineering must address, and which if exchanged later in the design or construction process, could significantly impact cost, time, or performance results.

Major Construction Methods

Major construction methods for building and industrial projects relate to: site grading and excavation; foundations; superstructure; enclosure; major building and process equipment; modularization; preassembly; and heavy rigging.

Timing, an interactive planning process, and measuring effectiveness are keys to constructability through major construction methods. Timing begins at project inception during the start of conceptual planning. All members of the project team interact and agree on the methodology that will quantitatively and qualitatively measure the output of major construction methods as positive construction contributors to overall project requirements.

Detailed design issues related to major construction methods are discussed later under Concepts II-2 and II-5.

Applications

Modularization. Special construction methods include prefabrication, preassembly, and modularization. This major construction method is attractive in certain conditions where local labor, resources, remote locations, or adverse weather are limiting factors.

Excavation. A high water table focuses special considerations on excavation and foundation construction. A common construction method used in high water table conditions is a well point or other method for dewatering. A well point system can be considered a major construction method because it can have significant implications in excavation, foundation design, and construction engineering.

Foundation systems. The choice of a foundation system is primarily determined by soils analysis. During evaluation of alternatives, each option's impact on construction operations to arrive at the most cost-effective method should be considered.

Modularization/Preassembly. Entire building floors including structural, architectural, mechanical, and electrical features could be preassembled on the ground and lifted into final position. Commercial or institutional buildings that consist of repetitive rooms or other features could use modularization.

Concept I-6: Site layouts promote efficient construction.

Discussion

This concept addresses the principle that construction efficiency is an important criteria in the layout of both permanent and temporary facilities.

Construction concerns often are neglected in the layout of permanent facilities, and the layout of temporary facilities is seldomly integrated with that of permanent facilities. Permanent facility layout should be reflective of construction concerns and well coordinated with temporary facility plans. When temporary facilities are not well thought out in advance and instead are "left to the field," the effects can be both costly and long-term. Temporary facilities are expensive project elements that can adversely affect construction productivity. They are too important to neglect.

Effective site layout can facilitate construction activities and thereby reduce cost in a number of ways, including:

1. Provide adequate space for laydown and fabrication yards and give serious consideration to the location of such yards relative to the work site. Consider the impact of adjacencies of and the efficiencies associated with flow and traffic patterns. Site temporary support facilities so as to avoid unnecessary relocation.
2. Facilitate access for construction equipment, materials, and personnel. In