Structural Systems

from Architectural Structures,
Wayne Place, Wiley, 2007:

STRUCTURAL DESIGN PROCESS

1.1 Nature of the Process

Architects have a huge array of issues to address in architectural practice. Among these are the following: keeping rain out of a building, getting water off a site, thermal comfort, visual comfort, space planning, fire egress, fire resistance, corrosion and rot resistance, vermin resistance, marketing, client relations, the law, contracts, construction administration, the functional purposes of architecture, the role of the building in the larger cultural context, security, economy, resource management, codes and standards, and how to make a building withstand all the forces to which it will likely be subjected during its lifetime. This last subject area is referred to as *architectural structures.*

Because of the extraordinary range of demands on an architect's time and skills and the extraordinary number of subjects that architecture students must master, architectural structures are typically addressed in only two or three lecture courses in an accredited architectural curriculum in the United States. These two or three lecture courses must be contrasted with the ten or twelve courses that will normally be taken by a graduate of an accredited structural engineering curriculum. This contrast in level of focus makes it clear why a good structural engineering consultant is a very valuable asset to an architect. However, having a good structural consultant does not relieve the architect of serious responsibility in the structural domain. All architects must be well versed in matters related to structures. The architect has the primary responsibility for establishing the structural concept for a building, as part of the overall design concept, and must be able to speak the language of the structural consultant with sufficient skill and understanding to take full advantage of the consultant's capabilities.

1.2 General Comments Regarding Architectural Education

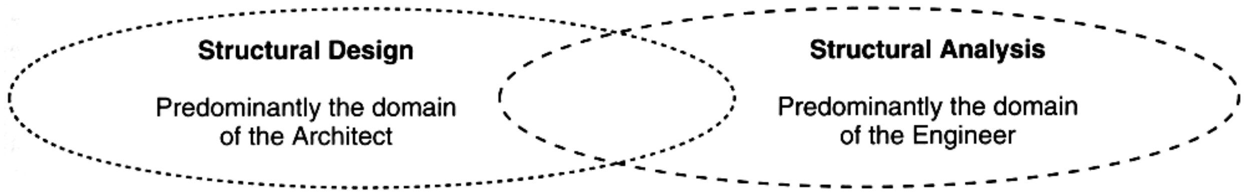
Structural design is one of the more rigorous aspects of architectural design. Much knowledge has been generated and codified over the centuries that human beings have been practicing in and developing this field. This book gives primary attention to those things that are known, quantified, and codified.

However, very few things in the realm of architecture yield a single solution. To any given design problem, there are many possible solutions, and picking the best solution is often the subject of intense debate. Therefore, no one should come to this subject matter assuming that this text, or any text, is going to serve up a single, optimized solution to any design problem, unless that design problem has been so narrowly defined as to be artificial.

In design, there is always a great deal of latitude for personal expression. Design is purposeful action. The designer must have an attitude to act. Architecture students develop an attitude through a chaotic learning process involving a lot of trial and error. In going through this process, an architecture student must remain aware of a fundamental premise: the process is more important than the product; that is, the student's learning and development are more important than the output. The student has a license to make mistakes. It is actually more efficient to plow forward and make mistakes than to spend too much time trying to figure out how to do it perfectly the first time. To paraphrase the immortal words of Thomas Edison: To have good ideas, you should have many ideas and then throw out the bad ones. Of course, throwing out the bad ones requires a lot of rigorous and critical thinking. No one should ever fall in love with any idea that has not been subjected to intense and prolonged critical evaluation and withstood the test with flying colors. Furthermore, important ideas should be subjected to periodic reevaluation. Times and conditions change. Ideas that once seemed unassailable may outlive their usefulness or, at the very least, need updating in the light of new knowledge and insights.

In pursuing this subject matter, it is valuable to have a frame of reference regarding the roles of the architect, as the leader of the design team, and the structural engineer, as a crucial contributor of expertise and hard work needed to execute the project safely and effectively. The diagram in Figure 1.1 will help provide that frame of reference.

In contemplating the diagram in Figure 1.1, keep in mind that design and analysis are two sides of the same coin and that the skills and points of view of architects and engineers, although distinctive, also overlap and sometimes blur together. The most effective design teams consist of individuals with strong foci who can play their respective roles while having enough overlap in understanding and purpose that they can see each other's point of view and cooperate in working toward mutually understood and shared goals. The most harmful poison to a design team is to have such a separation in points of view and understanding that a rift develops between the members of the team. Cooperation is the watchword in this process, as in all other team efforts.



Typical questions:
What should the form be?
What are the structural elements?
How do the elements fit and work together?

Characterizations:
Artistic
"Feelable"
Emphasizes "soul"
Intuitive
Learnable
Chaotic
Trial-and-error learning process
Idiosyncratic and individualistic

Typical questions:
How big do the structural elements need to be?
What grade of material do we use?
How strong do the connectors need to be?

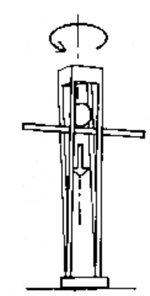
Characterizations:
Scientific
Knowable
Emphasizes "efficiency"
Analytic
Teachable
Orderly
Systematized
Generalized and codified

Figure 1.1 Nature of the design process and roles of the design participants.

Design Criteria for the Behavior of the Overall System

Components of a system consist of vertical and horizontal elements. Connections of the vertical to horizontal elements are also necessary. For the structural elements to behave and respond as designed, the system must have the following qualities:

- the components stay together
- the system resists overturning, sliding, twisting and excessive distortion
- the system has internal stability
- the system has overall strength and stiffness



Twisting

"Order" of Design

There is no set order to design of a structural system. But there are certain stages that can be recognized. These may be referred to as *preliminary, revised* and *final,* or more formally as:

First order: which can include determining structural type and organization, design intent, and contextual or programmatic emphasis. Preliminary member size charts are useful at this stage.

Second order: which can include evaluating structural strategies, choice of construction materials, and structural system options with those materials. System selection design aids are useful at this stage.

Third order: which, after the design has been narrowed down, is where analysis and design (shape and size) of individual structural elements (beams, columns, connections, etc.) is performed. The outcome here may direct further first order or second order investigations!!!

from Understanding Structures, Fuller Moore, McGraw-Hill, 1999:

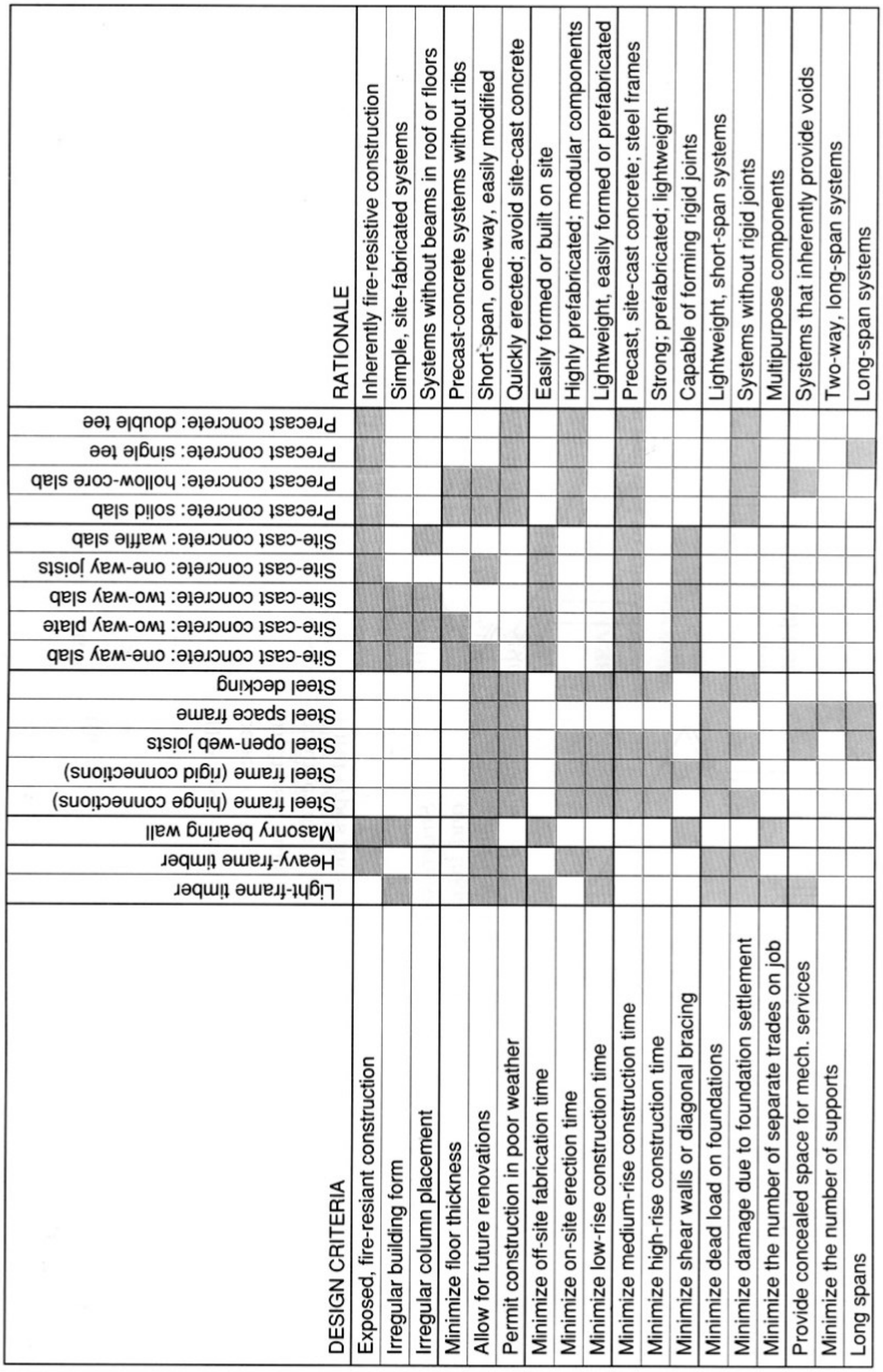


Figure 18.6: Framing system selection chart.

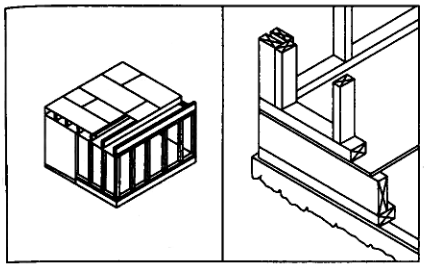
from The Architect's Studio Companion, 3rd ed., Allen & Iano, Wiley, 2002

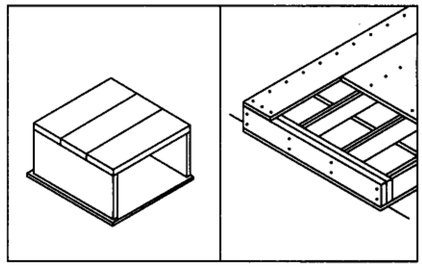
DESIGN CRITERIA: SUMMARY CHART

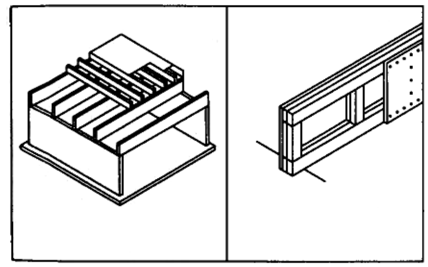
GIVE SPECIAL CONSIDERATION TO THE SYSTEMS INDICATED IF YOU WISH TO:	WOOD AND MASONRY				STEEL				SITECAST CONCRETE										PRECAST CONCRETE			
	Platform Frame (Pages 49–65)	Timber Frame (Pages 49–69)	Ordinary Construction (Pages 71–85)	Mill Construction (Pages 71–85)	Light Gauge Steel Framing (Pages 88–91)	Single-Story Rigid Steel Frame (Pages 102–103)	Steel Frame—Hinged Connections (Pages 87–105)	Steel Frame—Rigid Connections (Pages 87–105)	One-Way Solid Slab (Pages 114–115)	Posttensioned One-Way Solid Slab (Pages 114–115)	One-Way Joist (Pages 116–117)	Posttensioned One-Way Joist (Pages 116–117)	Two-Way Flat Plate (Pages 118–119)	Posttensioned Two-Way Flat Plate (Pages 118–119)	Two-Way Flat Slab (Pages 120–121)	Posttensioned Two-Way Flat Slab (Pages 120–121)	Waffle Slab (Pages 122–123)	Posttensioned Waffle Slab (Pages 122–123)	Solid Slab (Pages 132–133)	Hollow Core Slab (Pages 132–133)	Double Tee (Pages 134–135)	Single Tee (Pages 134–135)
Create a highly irregular building form	●		●		●				●	●			●	●	●	●						
Expose the structure while retaining a high fire-resistance rating		●		●					●	●	●	●	●	●	●	●	●	●	●	●	●	●
Allow column placements that deviate from a regular grid													●	●	●	●						
Minimize floor thickness										●			●	●	●	●			●	●		
Minimize the area occupied by columns or bearing walls						●	●	●									●	●			●	●
Allow for changes in the building over time	●	●	●	●	●		●	●	●		●								●	●		
Permit construction under adverse weather conditions	●	●			●	●	●	●											●	●	●	●
Minimize off-site fabrication time	●		●	●	●				●	●	●	●	●	●	●	●	●	●				
Minimize on-site erection time		●				●	●	●											●	●	●	●
Minimize construction time for a one- or two-story building	●	●			●	●	●	●														
Minimize construction time for a 4- to 20-story building							●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Minimize construction time for a building 30 stories or more in height							●	●														
Avoid the need for diagonal bracing or shear walls						●		●	●	●	●	●	●	●	●	●	●	●				
Minimize the dead load on a foundation	●	●			●	●	●	●														
Minimize structural distress due to unstable foundation conditions	●	●					●												●	●	●	●
Minimize the number of separate trades needed to complete a building			●	●																		
Provide concealed spaces for ducts, pipes, etc.	●		●		●																	

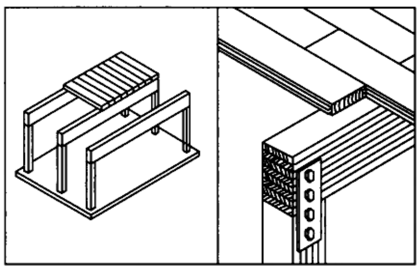
System Types by Material from Structures, Schodek & Bechthold, 6th ed.. Pearson, 2008:

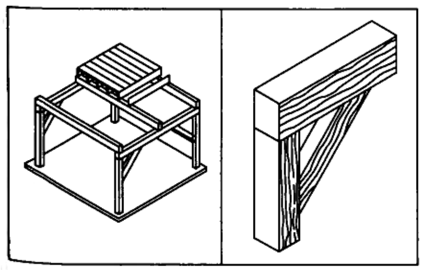
Timber Systems

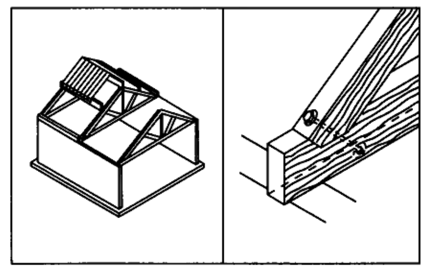

(a) Light frame construction.

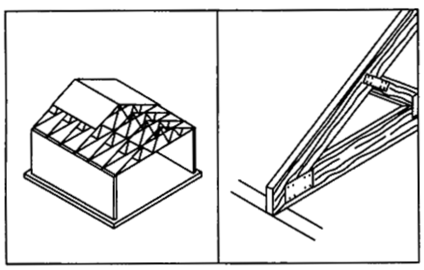

(b) Stressed-skin panels.

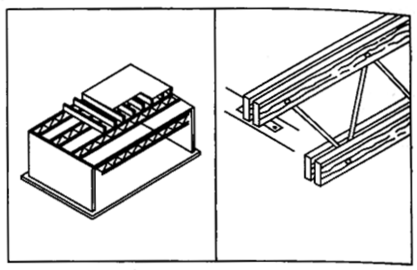

(c) Box beams.

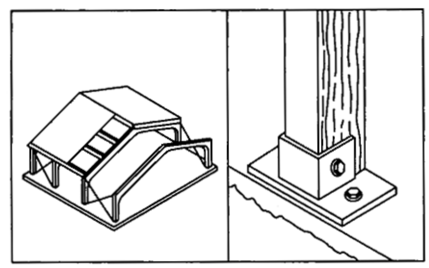

(b) Heavy timber construction: laminated beams.

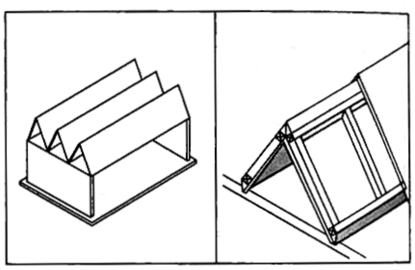

(e) Heavy timber construction: knee-braced frame.

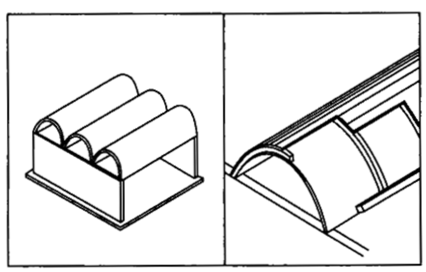

(f) Trusses: special designs.

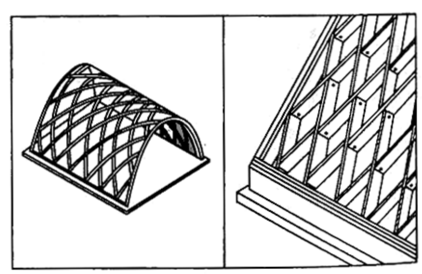

(g) Trusses: mass-produced "trussed rafters" for housing.


(h) Trusses: mass-produced open-web joists.

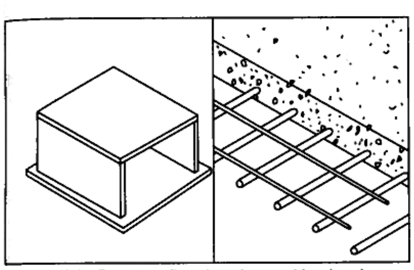

(i) Arches laminated timber members.

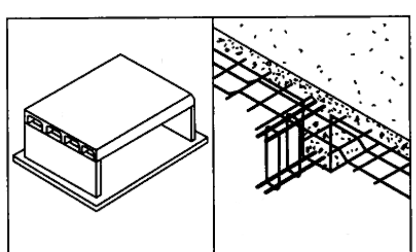

(j) Folded plates.

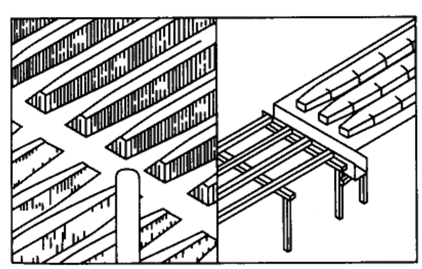

(k) Arch panels.


(l) Lamella construction.

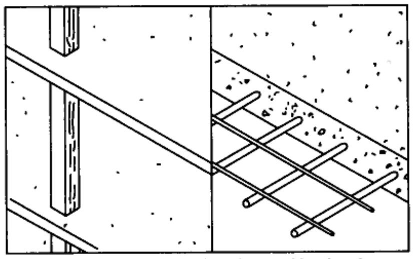
Reinforced Concrete Systems

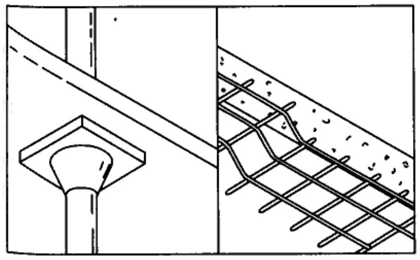

(a) One-way flat plate (poured in place).

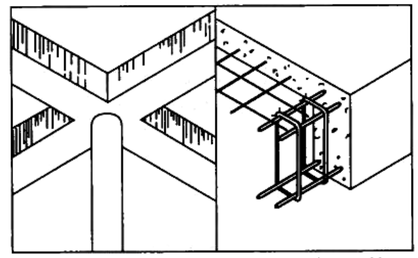

(b) One-way beam-and-slab system (poured in place).

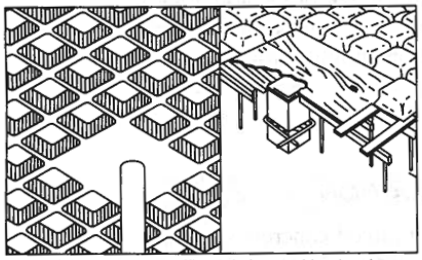

(c) One-way pan joist system (poured in place).

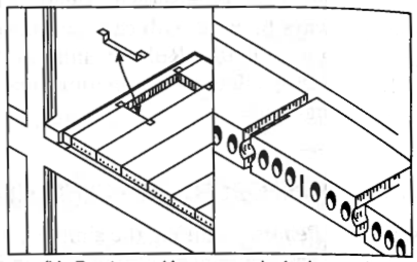
Reinforced Concrete Systems (continued)

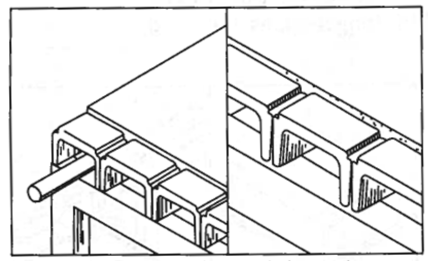

(d) Two-way flat plate (poured in place).

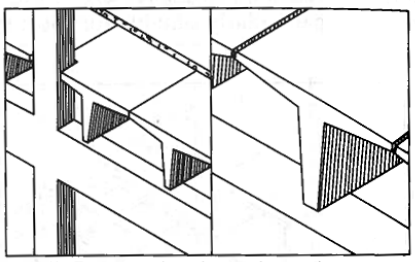

(e) Two-way flat slab (poured in place).

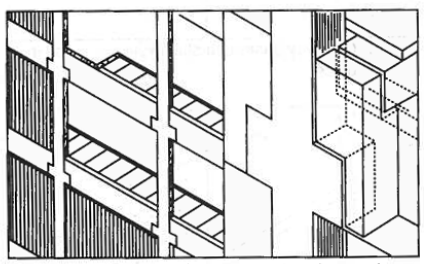

(f) Two-way beam-and-slab system (poured in place).

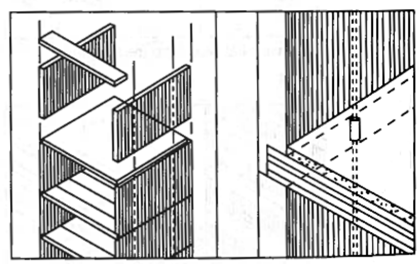

(g) Two-way waffle slab (poured in place).


(h) Prestressed long-span planks (precast).

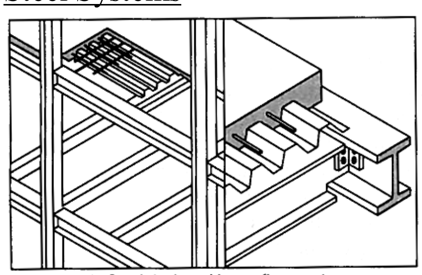

(i) Prestressed channels (precast).

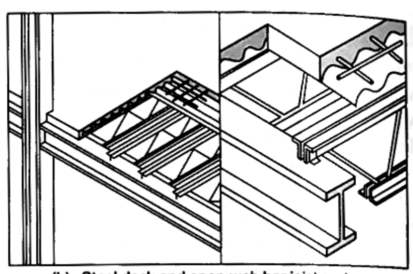

(j) Prestressed single tees (precast).

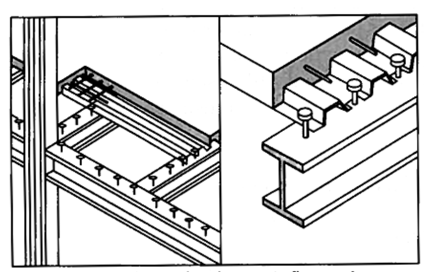

(k) Beam-and-column system (precast).

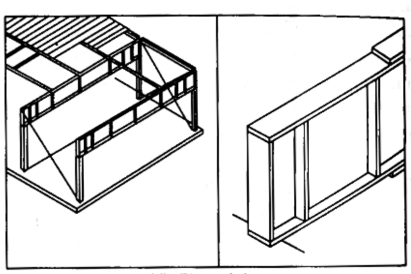

(l) Housing system (precast walls and planks post-tensioned together).

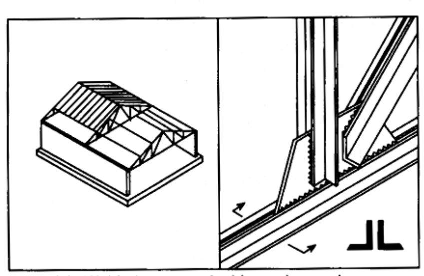
Steel Systems

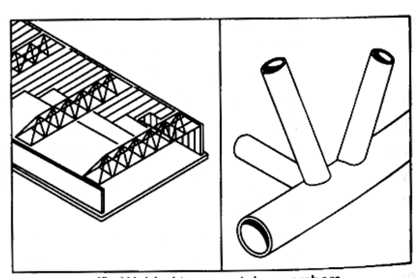

(a) Steel deck and beam floor system.


(b) Steel deck and open-web bar joist system.

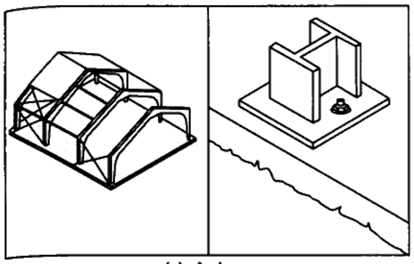

(c) Composite steel and concrete floor system.


(d) Plate girders.

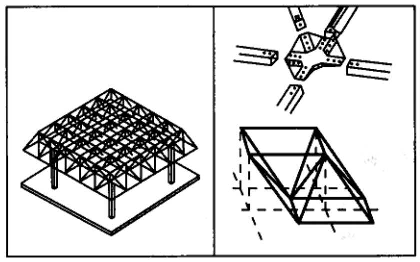

(e) Welded trusses: double-angle members.


(f) Welded trusses: tube members.

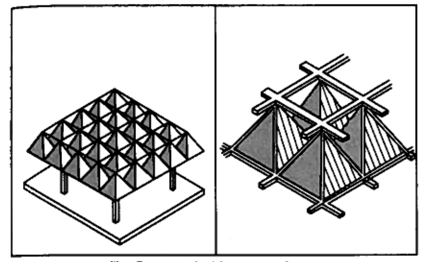
Steel Systems(continued)



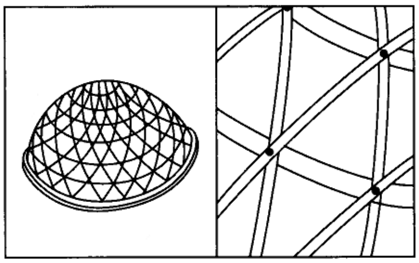
(g) Arches.



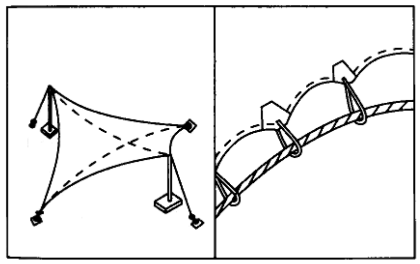
(h) Space frame.



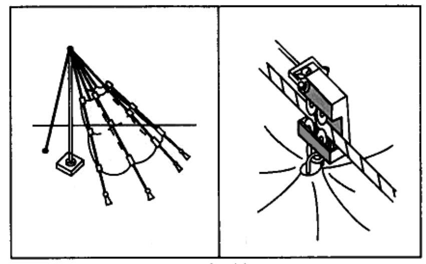
(i) Stressed-skin space frame.



(j) Ribbed dome.



(k) Prestressed membrane structure.



(l) Folding roof cable structure.