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Revision Memo

12/99	Highlights of this revision are: Update references to changed IPs. Update structural analysis - use of computer programs to reflect developments in software. Add recommendations to avoid water-catching crevices which have caused deterioration in the past.
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SCOPE

This section covers the structural conception and design of a wide variety structures supporting equipment in Refineries and Chemical Plants. Typical equipment support structures covered include exchanger structures, reactor structures, vertical tower structures, FCCU structures and silo structures. For pipe racks, machinery foundations and machinery support structures, see [Sections K, F, and G](#), respectively.

This section is intended for the design of new structures. It can also be used to assist in the analysis and modification/repair of existing equipment support structures.

REFERENCES

DESIGN PRACTICES

- [Section XXIX-D](#) Design Loads
- [Section XXIX-F](#) Machinery Foundation Design
- [Section XXIX-G](#) Foundations for Process Vessels and Equipment Structures
- [Section XXIX-K](#) Pipe Supports

INTERNATIONAL PRACTICES

- [IP 4-1-1](#) Concrete Design and Construction
- [IP 4-1-2](#) Structural Steel Design
- [IP 4-1-3](#) Design Loads for Structures
- [IP 14-3-1](#) Fireproofing

OTHER REFERENCES

- ACI 318 Building Code Requirements for Reinforced Concrete
- ACI 506 Recommended Practice for Shotcreting
- ACI SP-66 Detailing Manual
- AISC Specification for Structural Steel Buildings - Allowable Stress Design and Plastic Design
- ASCE 7 Minimum Design Loads for Buildings and Other Structures
- UBC Uniform Building Code

OBJECTIVE

This section provides a simple approach for the design of equipment support structures, including the design philosophy design considerations and criteria to be adopted. It also includes guidance on the calculation of design loads specific to equipment support structures. Design loads are covered more extensively in [IP 4-1-3](#) and in [Section D, Design Loads](#).

DESIGN CONSIDERATIONS

DATA REQUIREMENTS

The designer of the equipment support structure should work with other disciplines to obtain the best available information, to achieve a structurally sound, economical design. The following information should be gathered before design:

- Plant layout including the arrangement of process units, equipment, piping routes, existing and new roads, railroads, ditches, power lines, and underground obstructions.
- Electrical routes and support requirements, and zone classification.
- Equipment drawings including empty weights, operating weight, anchor and support requirements, test, erection, and maintenance requirements.
- Fireproofing requirements including materials, limits, and automatic sprinkler systems.
- Requirements for personnel access and evacuation (stair and ladder).
- Requirements for future expansion.
- Platform requirements.

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DESIGN CONSIDERATIONS (Cont)

- Location of large valves, steam pots, motor operated valves, etc., associated with the process piping.
- Cranes and davits.
- Height limits.
- Type of foundation.
- Soil or pile properties including allowable bearing pressure, lateral resistance, and settlement.
- Requirements for equipment erection and maintenance.

▶ DESIGN CRITERIA

Equipment support structure design should be based on the following data:

- Loads and load combinations.
- Allowable stresses and deflections.

FACTORS AFFECTING DESIGN

For a given design of equipment support structure, it is not possible to optimize all design factors simultaneously. Design is always a compromise within constraints. Some factors to be considered in the design process are:

- Safety and reliability.
- Function and serviceability.
- Maintenance.
- Cost.
- Speed of construction.

Safety and Reliability

The structure must be capable of sustaining the design loading safely and reliably. It must have the required integrity against total or partial collapse.

Function and Serviceability

The structure must be capable of performing its required function within the desired serviceability requirements. For example, the limiting deflection must be considered. It should also sustain long periods of service without degradation due to climate, chemical environment conditions, or loadings.

Maintenance

Future maintenance requirements should be considered in the initial design of the structure. This may require provisions for access to inspect and perform periodic maintenance.

Cost

The design should keep costs as low as possible. The following directly impact the cost of equipment support structures:

- Materials (selection of the appropriate type and grade).
- Construction methods (including labor, transportation, etc).
- Fabrication methods.

▶ Speed of Construction

Modularization, simple concepts, repetition of elements contribute to speedy erection which can help towards a quick start-up.

Significance of These Factors

The design of any structure is always a compromise of the individual design factors. For each project, the designer must prioritize design considerations. For a low-budget project, costs are the priority. Where parts of a structure are difficult to access, maintenance considerations may be the priority. For turn-around jobs, speed of construction will govern.

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DESIGN CONSIDERATIONS (Cont)

▶ MATERIALS

Construction materials are generally determined by cost, installation, fireproofing requirements and procurement.

Steel is preferred for complex and high structures, due to ease and speed of erection. It also allows easy modifications.

Concrete has the advantage of being already fireproofed. Concrete structures however take longer to build. Concrete is normally selected for one or two level structures supporting heaters, furnaces or heavy rotating equipment.

CODES AND STANDARDS

Equipment support structures should be designed to the project steelwork and concrete specifications. These are usually developed by the Contractor and reviewed by the Project Management Team and the NPQC Engineer. They should include the requirements of **IP 4-1-1**, *Concrete Design and Construction* and **IP 4-1-2**, *Structural Steel Design*.

For construction in the U.S.A. or in countries with no comparable standards, the following codes and standards should be used:

For steel structures: AISC Specification for Structural Steel Buildings - Allowable Stress Design, or Load and Resistance Factor Design

For concrete structures: ACI 318 Building Code Requirements for Reinforced Concrete

Local standards, of comparable quality to the above, may be substituted, such as the British Standards BS 5950 - the Structural Use of Steelwork in Building, and BS 8110 - Structural Use of Concrete.

STRUCTURAL FRAMING

An equipment support structure is an assembly of members subjected to bending or to direct force (tensile or compressive) or to a combination thereof. These may be accompanied by shear and sometimes torsion. Effects of changes in temperature, shrinkage and creep of the concrete, and the possibility of damage resulting from overloading, local damage, abrasion, vibration, frost, chemical attack, etc. may also have to be considered.

Members are connected to form a continuous structural frame, resist moments, forces and other effects. An efficiently designed structure is one in which the members are arranged in such a way that the weight, loads and forces are transmitted to the foundations by the cheapest (usually most direct) means consistent with the intended use of the structure and the nature of the site.

▶ LAYOUT

Simple structures contribute to a well-engineered plant. The engineer should try to keep the number of braces to a minimum and avoid unsymmetrical bracing and knee braces. Good appearance and space utilization is a part of good design and is a result of careful planning. For example, the floor beams should be located one above the other in multi-story structures. This produces economical repetition of members and also ensures that vertical piping will clear all beams.

The type of structural system and material selected can affect the space available for ancillary equipment and piping. Common structural systems are as follows:

Rigid steel frames resist lateral loads by bending of the beams and columns. Usually they require less members than braced structures. Appearance is excellent and maintenance costs are low. Rigid frames allow the most freedom for pipe routing and provide the best possible access. Rigid frames, when used, should generally be confined to the major axis of column members. Low, heavily-loaded rigid frames can often carry lateral loads with little increase in member size beyond that necessary to carry vertical loads. However, tall or lightly loaded rigid frames are usually inefficient.

Braced steel structures resist lateral loads by means of axial forces rather than by bending. Since the axial deformations are usually considerably smaller than bending deformations, braced structures are inherently stiffer than rigid frames. Multi-story steel structures should be fully braced, if practical. However, sometimes it is preferable to design a structure, which is rigid frame in one direction and braced in the other. One example is an exchanger structure where access is necessary for removal of tube bundles. In general, steel structures with height-to-width ratio of 3 to 1 or over 50 ft (15 m) high will require bracing.

Reinforced concrete structures generally do not require bracing to resist lateral loads, thanks to the rigidity of joints in monolithic beam-and-column construction.

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STRUCTURAL FRAMING (Cont)

STEEL STRUCTURES

Beams

Floor beams should be arranged such that the main girders (primary members) span in the short direction of the floor plan, if practical. The secondary members should span in the long direction of the floor plan, supported on the primary members.

The use of cantilevered beams should be considered in roof design, to save weight.

Do not design for minimum weight alone. This may require many different sections and connections and will be more labor intensive in shop and field. In particular, odd sections that may not be readily available, should be avoided. These could result in costly delays.

For heavily loaded members, all loads should be shown on the design drawings to avoid costly over-designing or dangerous under-designing of connections.

In a floor system, beam compression flanges may generally be considered to be fully-braced when a concrete slab is cast on the compression flanges, when checker plate is bolted or welded to the compression flanges, or when grating or metal decking is welded to the compression flanges. Bolted or clipped grating must not be considered as adequate compression flange bracing.

Vertical Bracing

Unless rigid frame design is adopted, vertical bracing is required to transfer lateral forces to the foundations.

"K" bracing or members resisting compression as well as tension are preferred to members resisting tension only. Tension-compression bracing is considerably more rigid, has better appearance, and provides more clearance for personnel and equipment. Braced structures subject to vibrations from equipment should be designed with tension-compression bracing members only.

Compression bracing should normally be designed with wide flange and structural tee shapes. For tension bracing, single angle or structural tees may be used. Double angle bracing should be avoided because it is difficult to protect adequately against corrosion.

In addition to lateral loads, "K" bracing, or inverted "K" bracing should be designed to transmit gravity loads from a beam to the column connections above or below. The beam itself should be designed as a continuous member across a rigid support.

"X" bracing should normally be used to brace hoisting facilities. The slenderness ratio of such braces should be limited to 200, due to the abrupt reversal of stresses which are characteristic of crane runs. Wide flange shapes and structural tees should be used. Rods and single angle bracing should be avoided. Bracing should not be connected directly to the underside of the crane beams.

Horizontal Bracing

Horizontal bracing is required to transfer lateral forces from the equipment to the column lines, without excessive distortion. It may also be required to prevent floor beams from twisting.

Horizontal bracing should be installed at the top level of the structure and at every equipment support level, unless a suitable diaphragm is available for transmitting lateral forces.

Avoid horizontal bracing connections at columns. It is difficult to make these connections without inducing torsion in the column. Horizontal bracing should be connected close to the loaded flange of a beam to transfer the load with limited beam torsion. Single angle or tee sections are normally used as horizontal bracing diagonals.

Floor beams used as chords of horizontal trusses should be designed for the axial load produced from the lateral loads, and the bending moment from the gravity loads.

Connections

Shop connections should normally be welded, field connections should normally be bolted. Welding of connections in the field should be avoided as far as possible. In addition, no field welding to vessels or other equipment should be permitted. When attachment to a vessel from a platform is necessary, lugs must be shop welded to the vessel by the Vessel Fabricator.

Connections will normally be designed by the fabricator in accordance with the project construction specifications and loads shown on the drawings. Moment and special connections, however, should be designed by the engineer and detailed on the drawings.

Moment connections should be shop welded or fastened with high tensile strength steel bolts, and include all rigid joints in framed structures, cantilever beams, and crane brackets.

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STRUCTURAL FRAMING (Cont)

Column splices at mid-story height should be avoided. These are often so high that erectors have to rig a float or scaffold. If the splice can be located up to 5 ft (1.5 m) above the steel beams, it will save extra rigging and, in general, still be in a region of low bending moment. Column splices need not be designed to develop the full strength of the smaller section, just the actual loads on the splice.

Bolted connections should, in general, be bearing type connections with threads excluded from the shear planes. However, slip critical connections should be used in connections subject to vibration or frequent stress reversal.

Use of High Strength Steel

For the design of steel equipment structures, ASTM A36 is generally the most versatile and economical of the construction steels. However, there are occasions where the judicious use of high strength steels can result in overall cost savings.

The use of high strength steels usually results in a reduced structural weight. If the weight reduction lowers the cost of foundations, handling, transportation, or erection, then high strength steels can and should be used.

High strength steels can usually be of benefit in tension members, except in relatively small sections or when bolt holes substantially reduce the net section of the member.

The use of high strength steels for beams could be of benefit when steel weight is a major portion of design load, and when allowable deflections do not determine section size. For columns and compression members, high strength steel should only be considered if the slenderness ratio of the member is small.

CONCRETE STRUCTURES

Columns

Reinforced concrete columns are generally rectangular in section with separate stirrups, or circular/octagonal with helical binding. Many factors enter into the design of a column, such that it is not easy to decide which combinations give the most economical member. However, in general the following may apply.

- The stronger the concrete the more economical is the column.
- For a square column the minimum amount of longitudinal reinforcement produces the cheapest member for a specified quantity of concrete.
- A square column is generally less costly than an octagonal column with helical binding.

Beams and Slabs

Concrete floors may be of monolithic beam-and-slab construction (the slabs spanning in one or two directions), flat slabs, ribbed or waffle slabs, or may be of precast concrete slabs supported on cast on site or precast concrete beams.

Beam sizes should be standardized as far as possible. It is best to keep the beam as wide as the column into which it frames. Mixing rebar sizes for the main reinforcement should be avoided. A symmetrical rebar pattern is preferable. The concrete beams supporting the equipment must be deep enough to accept the equipment's anchor bolts. Interference between anchor bolts and main reinforcement should be checked. Rebar interferences must be checked where two beams frame into a corner column at the same elevation.

Slabs supported on two opposite sides only (one-way slabs) behave as beams, and are designed, due account being taken of continuity. If a slab is nominally freely supported at an end support, it is advisable to provide resistance to a probable negative bending moment at a support with which the slab is monolithic. Although a slab may be designed as spanning in one direction only, it should also be reinforced at right angles to the span with at least the minimum proportion of rebar to ACI 318.

When a slab is supported on more than two opposite sides (two-way slabs), the precise amount and distribution of the load taken by each support, and consequently the magnitude of the bending moments on the slab, are not easily calculated. The design method in any particular case depends on the shape of the panel of slab, condition of restraint at the supports and type of load. Two basic methods are commonly used to analyze slabs spanning in two directions. These are **the Theory of Plates**, which is based on an elastic analysis under service loads, and **Yield-line Theory**, in which the behavior of the slab as collapse approaches is considered.

Distinction must be made between the conditions of free support, fixity, partial restraint and continuity. It is essential to establish whether the corners of the panel are free to lift. Free support occurs rarely in ordinary reinforced concrete beam-and-slab construction, the slab is monolithic with the beams and not free to lift at the corners. If the edge of the slab is built into a substantial brick or masonry wall, or is monolithic with concrete encasing steelwork or with a reinforced concrete beam or wall, partial restraint exists. Continuity over a support provides restraint less rigid than fixity: the rotation of the slab at the support depends on the load, on the panel and on adjacent panels.