FRAMING SYSTEMS FOR MICROELECTRONIC FACILITIES

Fast track construction and mechanical system design play a crucial role in selecting a suitable framing system

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MICROELECTRONICS FACILITY STRUCTURAL STEEL FRAMING SYSTEM SELECTION can be driven by an ambitious fast track design schedule for material fabrication, delivery and erection, longspan framing requirements for column free manufacturing space and vibration sensitive design criteria. Further, mechanical loads may not be well defined at the outset of design precluding the use of steel joist roof framing systems. Microelectronics Facility Design is not driven by architectural considerations as much as by mechanical system support requirements.

Microelectronics facilities are very specialized, single-use, high-bay facilities which typically incorporate long span trusses, extraordinarily sensitive vibration design criteria, and very heavy permanent equipment loads. Fab buildings, as they are referred to in the industry, are typically three-story structures ranging in size up to 300,000 sq. ft. Typical project costs are on the order of one billion dollars, which includes very costly process equipment or “tools”. Construction cost may be 30% to 40% of the total. The microelectronics industry is very dynamic and product life cycle can be very short. Technological advances require owners to design, build, staff, qualify tools and begin operation in increasingly shorter periods of time. Lost days in production can cost millions of dollars a day. Most microelectronics fabrication (fab) facilities are designed as fast track design-build projects and redefine the term fast track to hyper track. It is not uncommon for mill order drawings to be produced within the first couple of weeks of design for advanced mill order of rolled shapes.

Microelectronics facilities are classified by the Uniform Building Code as hazardous occupancy facilities. This hazardous occupancy classification can lead to explosion venting design and damage limiting construction for areas used for storing volatile gasses subject to conflagration. Further, the code requires an importance factor of 1.25 be used in the seismic analysis of the structure. Dynamic analysis are not immediately required due to the H occupancy classification but may be required due to building stiffness irregularities.

CONFIGURATION OVERVIEW

Fab buildings are typically three-story structures. The ground floor (or basement level) is referred to as the “sub fab” and houses a tremendous volume of support mechanical equipment. Above the “sub fab” is the “process level” or clean room area and adjacent personnel and equipment support areas. The clean room space can be on the order of 60,000 to 80,000 sq. ft. and is typically isolated from the adjacent structure with a physi-

Long-span trusses provide a mechanical equipment floor level, lateral load resistance and column-free manufacturing space. Photo by Steve Miller, KPFF

cal isolation joint to preserve the extreme vibration sensitivity of the space. Clean rooms are classified based on various classes of air purity, class 1,10,100, and 1000. This classification represents the number of .5 micron particles per cubic foot of air. The process level fab environment is extremely sensitive to micro-contamination and is usually class 1 or 10 space. The third floor or "fan deck" level houses mechanical equipment for: air purification, space conditioning, uninterrupted power supply and electrical transformers and switch gear. The fan deck is typically the bottom chord level of full story depth long span trusses spanning across the process clean room or "ballroom" as it is sometimes referred. The roof level is framed at the top of the "fan deck" trusses.

Framing Overview

Long span trusses provide for column free space in the primary fabrication (clean room) areas, provide for the support of a myriad of air purifying mechanical equipment, and serve as lateral load resisting elements transferring roof seismic and wind loads through their depth.

The Process area floor is usually designed as a concrete waffle slab (or waffle grid) supported by concrete columns and shear walls. Composite floor framing may be used for the bulk of the floor plate (outside the process area) design. The economy provided with this common structural system is very similar to that of commercial office building design but can be even more equitable due to the relative high design live loads. However, numerous penetrations through floors are required for ducting which can compromise a composite floor design. Mechanical systems may not be well developed at the outset of structural design and it is not uncommon to cover plate beams and modify connections after steel erection is complete to accommodate unexpected floor penetrations, the loss of composite action and unexpected loading.

Roof framing members (spanning between trusses) can be rolled shapes or open web joists. Rolled shapes provide much more flexibility for hanging loads due to the fact that mechanical system piping and duct runs may not be determined until the design is nearly complete. The use of open web joists could potentially require costly field modifications for the support of concentrated mechanical loads. Design-build mechanical systems can be slow to develop given their extreme complexity and sensitivity to ever changing equipment specifications. Beams with fabricated web openings provide an economical substitute for roof joists (and floor beams) an will be discussed in greater detail later.

Three levels of structural framing showing "Fan Deck" and roof framing with open-web expanded beam framing.

Lateral Load Resisting Systems Overview

Lateral loads generated from; seismic loads, wind loads and blast loads, may be resisted by a number of different types of well known bracing systems, but are most economically resisted by braced frames located on the building perimeter (unlike developer office building projects) and throughout the interior. The number of braced frames required is proportionately larger for microelectronics facilities than for commercial office buildings due to the inertial mass created by the large volume of permanent mechanical equipment and heavy composite slabs designed to support equipment loads. Numerous braces will also reduce the load to "long" braces at tall floor to floor areas thus reducing the brace sizes and foundation loads. Code prescribed buckling criteria can play a significant role in determining brace sizes. Braced frames often extend through occupied spaces. This can dictate the brace geometry; "Chevron", "V", or single diagonal. Moment frames require excessively large column sections due to tall floor to floor dimensions and Uniform Building Code (UBC) building drift limitation requirements.

Design lateral loads are specified in the UBC for building design in the Western United States. Code prescribed seismic forces must include an importance factor of 1.25 as specified for hazardous facilities. The UBC specifies that for warehouse facilities a percentage of permanent equipment load be accounted for in the lateral analysis. The calculated equipment load weight can be significantly higher than the UBC prescribed mass. It is prudent to calculate the actual equipment weight, within reason, and include this mass in the lateral analysis.

The analysis of structural diaphragms can be quite complex. At the roof level diaphragms span between long span trusses which minimize shear loads and provide a very good load path to the fan deck level. Roof diaphragm shear loads produced from loads perpendicular to the truss span direction are resisted by full height perimeter braced frames.

Fab facility tools require a tremendous volume of air flow to provide an ultra pure clean room environment. This requirement creates large vertical plenum spaces throughout the structure and through (fan deck) structural diaphragms. Fan deck diaphragm shears are transferred through heavily reinforced "shear piers", which provide diaphragm continuity. Heavy composite slab reinforcing may be required to strengthen structural diaphragms. Diaphragm continuity can also be accomplished in narrow piers with the use of flat plate steel elements analogous to horizontal steel plate shear walls.

Service Load Design Criteria

The design live load criteria varies throughout microelectronics facilities and can be quite different. The process floor (clean room) structure is typically designed for a minimum 250 psf floor load for the support of fab tools and an additional 50 -100 psf for hanging loads incorporating; ducting, piping, and ceiling systems. This load may also be in the form of interstitial framing supporting mechanical equipment between the Sub Fab and Fab levels. Fan deck areas supporting air purifying equipment are typically designed for 100 to 150 psf which also includes; ceiling filter systems, ducting, and mechanical piping loads. Areas designed to receive electrical transformer and uninterrupted backup power equipment should be designed for a minimum 200 psf live load.

Roof areas should be designed for a minimum 50 psf live load for hanging duct work and piping but can also support heavy mechanical equipment which would need to be accounted for accordingly. Roofs can be subjected to internal plenum pressure loads resulting in net uplift loads (especially when added to wind uplift loads) requiring special attention to the bracing of beam flanges that are typically stressed in tension. Corridors and personnel support areas are typically designed per code minimum live load requirements. Support areas may become part of a future expansion within the fab and this should be taken into account when configuring floor loads. It may be prudent to design all floor areas for equipment loading.

Microelectronics facilities use hazardous chemicals throughout much of the wafer fabrication process. Facilities known as Hazardous Production Material (HPM) buildings, which are intended for the storage of flammable gasses, must incorporate very specialized blast relief damage limiting design. The design of HPM buildings is a topic of its own and will not be discussed in detail, but the loading criteria is quite interesting and noteworthy. The storage of volatile chemicals is usually in a separate adjacent building. Blast relief vent panels are required to relieve internal pressures and may be designed in roof structure and wall areas. Design loading can be as much as 150 psf on internal walls. Roof panels are typically designed to blow off at 40 psf. Design blast pressure is a function of the volatility of stored gasses. This creates many special design considerations not only with regard to the unbraced length of beam member compression flanges, but more importantly the overall structural stability of a building system.

HPM buildings storing chemicals and gasses subject to conflagration are typically single story concrete masonry buildings with steel roofs. Roof areas designed as blast relief panels have limited diaphragm capacity. Blast relief roof panels incorporate specialized fasteners which limit diaphragm capacities and allow for venting to occur at about 40 psf internal pressure. Lost diaphragm capacity must be replaced by inplane roof trusses (bracing) supporting exterior (and interior) masonry walls.

Structural System Selection (Gravity Framing)

Many different structural systems have been used for microelectronics facilities, and include: conventional reinforced concrete, precast concrete and composite/non composite steel framing. Choosing an appropriate structural framing system requires special consideration of many unique design parameters, material availability, and the economics of fast track construction. This article will focus on steel design, component selection and construction.

Conventional wide flanged rolled, domestically produced, structural shapes can be typically used for the structural frame, including long span truss chord and web members. Truss webs can be structural tubes or wide flange shapes depending on the magnitude of loads and types of connections desired. Web member tube sizes should be limited to TS12x12 to avoid cost premiums and potential availability problems for less than mill order quantities. A microelectronics facility structural floor framing grid is similar to a commercial office building's at approximately thirty two feet square. As mentioned above microelectronics facilities are typically high bay structures. Most economic column shapes are typically rolled wide flange shapes. Steel column supported long span trusses can produce column axial loads on the order of 700 - 1000 kips. Columns can range in size from W14x90 to W14x211 depending on tributary areas supported, braced frame locations and configurations.

Floor framing members designed as composite members (for 32 ft. bays) will typically be W18s or W21s, depending on the deck span (trib. area) with W24 or W27 girders. The use of composite beam design should be carefully considered. Microelectronics facilities are large mechanical system warehouse type facilities. With that comes a tremendous volume of mechanical equipment and associated floor penetrations. It may be prudent to design composite beams with one half the compression flange effective, as for a spandrel beam (B_e = ⅛ or beam spacing/2). This will accommodate a penetration adjacent to a beam or penetrations either side of a member with a predetermined concrete compression flange width between openings. A plan note on the drawings indicating the design parameters used will protect your design and alert the contractor to potential deviations from the original design if openings are other than as assumed (and shown on the contract documents) at the completion of construction documents. Composite steel deck will typically be 18 or 20 gage with 3-¼" light weight topping to produce a two hour fire rating. If a one hour rating is required normal weight topping can be used. The topping thickness will most likely be no less than 3" to produce the required live load carrying capacity. The choice of fire proofing systems is not only a code issue, but also a microcontamination issue that needs to be discussed early with the designers of the fab mechanical/process system. Beams and columns may be wrapped with sheetrock to achieve the desired fire rating. The economics of using light weight topping is an issue that also needs to be discussed early in the design process, and for design build projects can easily be handled by the construction manager/general contractor.

The support of air purification high-efficiency particulate attenuation (HEPA) filter ceiling grid systems can present unique design challenges not only from a structural support and seismic bracing concern but also from a structural beam design standpoint. Structural framing members supporting (above clean room/below fan deck) ceiling systems must be designed to avoid torsional lateral buckling from unbraced compression flanges. Designing for the full length as unbraced can produce uneconomically large members. It has been found that that adding intermediate bracing members significantly reduces member sizes (as

Truss bottom chord drag strut connection

would be expected). This presents additional design challenges in detailing intersecting beam connections to provide adequate bracing. Collecting bracing loads and accounting for ceiling system seismic bracing forces need special consideration since interstitial framing levels are not continuous by means of a structural diaphragm. Loads must ultimately be transferred to a rigid diaphragm for redistribution to braced frame members.

Similar problems are present at the roof. The interstitial space above the fan deck is a pressurized air plenum. This internal pressure can produce compression in flanges of roof framing members which are typically stressed in tension. This is especially true if the design architect chooses a (relatively light) single ply adhered membrane roof in lieu of a ballasted mechanically applied roof or more conventional built up roof system. For open web joist roof systems this can lead to increased chord member sizes and additional uplift bridging. For beam framed roofs member sizes would need to be checked for net uplift loads on the unbraced length.

The selection of roof framing members can be influenced by several different factors. Economics will always play a major role in structural member selection. Roof members of microelectronics facilities typically need to support heavy piping, ceiling, and ducting loads far in excess of commercial type office buildings. The uncertainty of all mechanical loads at the outset of design produces another unique design consideration. Rolled wide flange shapes can more easily accommodate point loads from mechanical support hangars than open web joists. Joists designed to accommodate .5kip to 1kip point loads any where along the joist length may produce uneconomically large chords sizes. However, rolled wide flange beams designed for 50 to 80 psf live load can better accommodate equipment point loads which are usually a moving target during design. Fabrication facilities can house large air handling and mechanical equipment in a separate central utility building (CUB), or much of this type of equipment can be roof top mounted. Water purification equipment usually is housed in a separate facility.

An economical option exists in using beams with web openings in lieu of conventional rolled wide flange shapes. The design of beams with web openings is beyond the scope of this paper, but an introduction to the fabrication method and analysis is important.

A repetitive pattern of hexagonal web openings are created by cutting a member longitudinally and then off setting the two halves to create a beam with up to 50 percent increase in depth and with the same weight. The resulting section has a much larger moment of inertia and section modulus. As an example a W18x35 beam can be (re) fabricated into a W24x35 or W27x35 with a large increase in stiffness and no change in weight. The lightest (conventional) W24 and W27 beams weigh 55 and 84 pounds per foot respectively. This equates to a weight savings of 36% and 58% respectively. With the use of automated computer controlled torches and welding apparatus this procedure has been found to be quite economical and can more than offset the cost of the heavier sections. Connections to adjacent framing members are no different than for conventional rolled shapes. Intersecting member connections to beams with web openings can be accommodated with full depth shear tabs if connections layout on a web opening.

Beam analysis is similar to that of a beam with a web opening for a mechanical pipe or duct. Top and bottom chord sections are analyzed a tee sections. The beam is sized based on the section modulus required to resist the maximum design bending moment. Secondary stress are then analyzed at the web openings. The beam acts similar to a Vierendeel truss. Combined stresses from the tee section axial load and secondary bending from the shear stress across the web adjacent to the opening are checked against AISC interaction equations. Shear stresses are checked over the gross section and the net section at the web opening.

Horizontal web shear flow is also checked at the web post between openings.

Beams with web openings can be composite or non composite and are an economical substitution for open web roof joists or rolled shape roof beams. Roof beams need to be braced during steel erection no different than conventional framing. Bracing is required based on the unbraced length of the compression flange and expected construction loads. Uplift bridging is no different than the required bracing for conventional rolled shapes or open web joists.

Lateral Load Resisting System Selection

For structures designed in the western part of the United States, lateral loads are derived as prescribed in the Uniform Building Code. West coast facilities are designed for seismic Zone 3 or 4 loading, while plants in the south west are designed for seismic Zone 1, 2, or 2b loading. The design differences are considerable and are beyond the scope of this paper. This paper will discuss the design of facilities designed in seismic Zones 3 and 4.

Microelectronics facilities are classified by the UBC as H (Hazardous) occupancy buildings. The Uniform Building Code dictates that hazardous facilities be designed with an importance factor of 1.25 times the prescribed earthquake loading and 1.15 times the prescribed wind loading. Design loading used for the analysis of equipment bracing is to incorporate an importance factor of 1.5. Further, facilities with permanent equipment should be designed to account for 25% of the permanent equipment mass in the seismic analysis as required by the UBC. It is prudent to calculate the actual expected mass of permanent equipment and compare that to the UBC criteria. The actual equipment weight may be considerably more and should be accounted for in the seismic analysis of the structural frame.

As noted previously, long span trusses provide for column free fabrication space. Truss gravity loads are relatively heavy and therefore a truss spacing of 32 feet (matching the structural building grid) will provide for economic members sizes. Trusses also serve well as lateral load resisting (transferring) elements. Seismic forces resisted parallel to the span direction of long span trusses can be collected in very stiff truss elements and transferred to (interior) braced frames. Truss analysis and detailing must account for seismic collector (drag) loads. Interior bay braced frames are inevitable and must be located accordingly. Interior braced frames may terminate at the truss bottom chord floor level.

Braced frames resisting seismic loads perpendicular to long span truss bays are typically located on the exterior building grids, but may locate on interior grids as required. The designer will not have the benefit of trusses as collector elements and braced bays would need to extend full height to the roof level. Diaphragm shears for loads perpendicular to truss bays will be considerably higher for brace bays located only at the building perimeter.

Microelectronics facilities are quite rectangular in plan. The layout of process equipment is linear and building plan aspect ratios can be between 1.8:1 to 3:1. The choice of braced frame locations is not as sensitive as in speculative office building design work. Frame locations, in heavy fabrication facilities can be governed by limiting diaphragm shear capacity, foundation/frame overturning (column) loads, and the magnitude of brace loads. In high bay structures brace member lengths can dictate the use of large tube or wide flange members. The UBC limits the "Chevron" brace slenderness ratio, Kl/r, to $720/\sqrt{F_y}^{1/2}$. For long braces this quickly eliminates many tube sizes. The UBC also requires, in seismic Zones 3 and 4, that connections have the "strength" to resist $3R_w/8$ times the calculated brace force. For braced frame structures the ductility factor R_w is equal to 8. These factors must all be considered in the schematic design phase of a project design while choosing braced frame locations. Of equal importance is the overall stiffness of the structure. Ample well throughout frame locations equally resisting a proportionate share of the structure base shear will limit building drift and minimize stiffness irregularities.

Lateral forces may be resisted by a number of different framing systems. The most economical system for high bay, heavy loaded structures is a braced frame "Chevron" or "V" brace configuration. Economy can be gained, with these configurations, from the brace length, frame geometry, and the fact that braces work in tension and compression. The UBC dictates that "Chevron" braces be designed for 1.5 times the calculated force, in part, to lessen the chance of a tension member failure resulting in compression buckling of the remaining brace. "V" braces, or inverted "Chevron" braces can be used in lieu of "Chevron" braces to help accommodate corridor door locations close to grid line columns or mechanical duct work centered in a corridor. This type of brace configuration requires special foundation considerations where braces meet the slab on grade between columns. The use of single diagonal braces is limited by the code. Design forces for single diagonals must be increased by $3R_w/8$ to account for the non redundant nature of the frame. The overall brace length and increased design load makes this type of frame system uneconomical and left to be used only when architectural or mechanical duct routing requirements dictate.

Moment frames are not particularly economical for high bay heavy loaded structures. This framing system yields heavy col-

"Fan Deck" long span truss bay with open-web expanded beam roof framing

umn and beam sections. Heavy structure loads would increase the number of frames required to limit member sizes and control building drift. The complexity of post Northridge moment connection field welding has recently created schedule problems on fast track projects not only due to increased field welding but also as a result of more stringent inspection criteria. Further, considerable ongoing review and testing of moment frame connections continually produce new information regarding design, detailing, and material specification requirements.

It is not uncommon for braced frame bays to be assembled on the ground and lifted into place. This gives the steel erector a means of controlling the building erection tolerances and economizes the fit up eliminating awkward position welding of brace members.

LONG SPAN TRUSS DESIGN

Trusses spanning across clean room areas provide for column free manufacturing space. A steel weight penalty is paid for clear span trusses in lieu of shorter multi-span continuous trusses. Clean room process equipment is extremely vibration sensitive and the introduction of a mid span truss column presents a vibration isolation problem which precludes the use of the process level to reduce truss column unbraced lengths. Truss depths are typically a full floor to floor story depth, a minimum of 15 feet. The bottom chord level or fan deck provides support for air purification equipment. Total truss load including fan deck and roof can be in excess of 300 psf. Truss chord and web members are typically wide flange and tube shapes depending on the load magnitudes and member lengths to achieve the best economy. Economy in truss design, as it relates to the overall steel erection sequence, is not only a function of the truss weight, but in the ease (or complexity) of: web and chord connections, attention to detail of intersecting secondary floor and roof framing members, zero tolerance truss to column connection details, and top chord bracing requirements to control "tl" buckling.

Truss chords at web intersection node points "picking" up floor and roof secondary framing members may be congested with stiffener plates which control truss chord web buckling problems. Special attention must be paid to the ease of connection of intersecting beam framing members. "Standoff" connections, or extended shear plates may be required to physically enable the erector to install beams and make bolted connections.

Many factors affect the design and analysis of long span trusses. Truss depths, to optimize efficiency, should be limited to approximately one tenth of the truss span. There is a diminishing return in optimizing chord sizes by increasing the depth to reduce axial loads. Compression members increase in size with increasing length governed by slenderness Kl/r. Chords are usually not parallel in order to provide a minimum roof slope. It may be desirable from an owners standpoint to slope the bottom chord. This bottom chord slope allows for accidental spills to "roll" off the truss into adjacent plenum space instead of possibly down into clean room fabrication space. Midspan camber may be desirable to offset dead load deflections.

Truss geometry can take any number of forms based on the designers preference, but may also be governed by mechanical duct size penetration requirements. Large mechanical ducts and a myriad of pipes extend through trusses. This requires that truss web member gusset plates be drawn to within as little as ½" of actual size for multiple computer aided design (CAD) overlay for mechanical coordination.

The move in, and replacement, of large mechanical equipment in the fan deck truss bays is a very important design consideration and not usually a concern in commercial buildings. Several options have been tested to accommodate equipment move in: roll up doors between truss bays at the building exterior, cantilever trusses with beam infill framing or Vierendeel trusses to provide openings transverse to their span. Design requirements for microelectronics facilities typically require access to concealed truss bay spaces after the design is complete. Access to concealed spaces can be accommodated with removable wall panels. Removable roof panels are not an especially good option for obvious reasons. Exterior bays with braced frames can be designed incorporating removable braces with bolted connections.

There are many variables involved in the erection of long span trusses. Field splices of shop fabricated trusses are almost inevitable due to shipping limitations. This requires field welding of at least one truss diagonal web member to complete the assembly. High strength bolted chord splices are typical. The addition of plates either side of the chord member web, above the bottom flange and below the top flange will, create a double shear connection. Locating the splice as near to the center of the truss or the calculated point of zero shear will reduce the web connection requirements. Analysis and detailing of trusses to bear on top of supporting columns will aid the steel erector with stability problems during erection. Fit up tolerances of truss (or braced frame) web connection plates to support columns is always of concern to the steel erector.

The analysis of long span trusses can be made using well understood design principles. Special attention must be paid to the design of web and chord connections. It is recommended to minimize web and chord sections as internal forces dictate. But, member lengths should be maximized to reduce the number of costly full penetration splices. Sophisticated design programs are available to simplify design. If trusses are modeled the author recommends fixing the web members and designing connections with the appropriate fixed end moment. Truss elements have continually been designed as two force members, but some fixety exists at the web to gusset plate connection point which should not be ignored. The percentage of web moment to overall (axial) load will typically not control the design. Chord members should align at mid depth to reduce excessive transition welding at adjacent (offset) flanges of chords with different thickness. Aligning chord depths will produce steps at the top of the top chord which may require the addition of shim plates to provide for a uniform bearing surface for roof decking. All of these suggestions will help produce well engineered, efficient, cost effective designs.

Connection design and detailing is of particular importance and worth some further discussion. The design of truss web connection gusset plates can provide interesting challenges. Aside from the shear and moment checks that must be made to preliminarily size gusset plates and welds, plates must be designed as column compression elements. Web members may be held up off of the truss bottom chord so as to not interfere with metal deck installation. Gusset plates must be sized for axial compression loading. This short plate column section can increase in size very quickly as web member end distance increases from the chord. The column being designed has a radius of gyration of $\sqrt{d/12}$, or 28.8 percent of the gusset plate thickness. This grossly limits the axial load carrying capacity of a plate column even with a very short length.

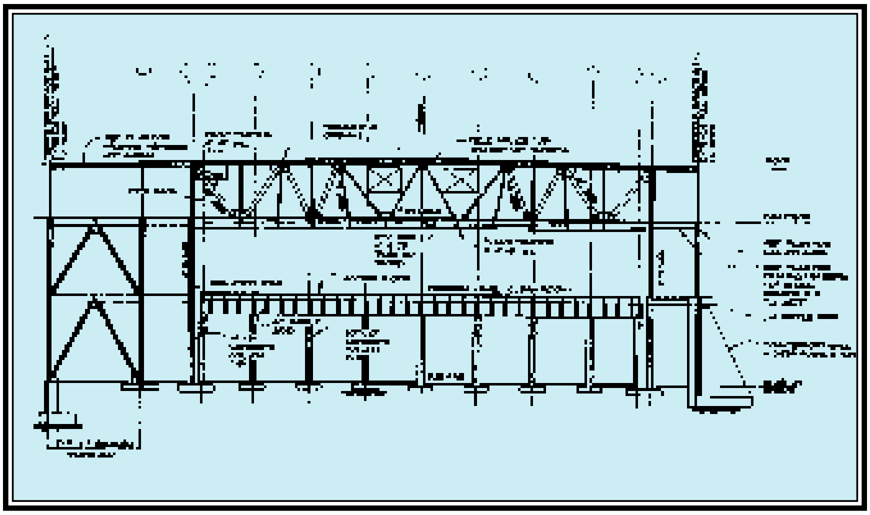
The choice of an appropriate "K" value to determine the design column length must be determined. A "K" of one is clearly unconservative and a "K" of two (as for a cantilever column) is clearly way too conservative. This author recommends using a "K" of 1.2. Stiffeners can be added to the each side of a gusset plate to change the "column" geometry and increase the "column" radius of gyration. This will help force plate shear, not compression buckling to govern the design. An economical advantage exists in detailing web members with square cut ends rather than parallel to the truss chord which should be accounted for in the gusset plate design.

Special attention must be paid to the unbraced length of truss top chord compression members. Intersecting beam connections may be detailed to provide adequate compression member bracing. Open web joists do not provide adequate top chord bracing because the bottom chord flange is not restrained in a typical bearing connection. Specially detailed top chord, bottom flange bracing is required to economize top chord member sizes and provide structural stability of the system. Contract documents should explicitly instruct the contractor on the appropriate erection sequence of truss top chord bracing as roof construction proceeds. It is not unusual for long span trusses with light single ply roofing systems or standing seam metal decks to experience load reversals with bottom chords in compression from wind uplift loading. This is not the case in microelectronics facilities with fan decks at the bottom chord level, but more prevalent in large single story high bay manufacturing buildings. For trusses with net uplift "problems", bottom chord diagonal bracing may be required up to an adjacent truss top chord to provide structural stability.

Vibration Criteria

Many papers have been written on vibration analysis and the derivation of applicable imperical formulas to assist engineers in the design of floor systems, avoiding perceptible vibrations. It is not the intent of this article to re-introduce vibration design criteria for buildings, but to discuss the uniqueness of microelectronics facilities' vibration design parameters and investigate a structural steel framing system suitable to replace a conventional concrete waffle slab floor system.

Microelectronics facilities



require extremely vibration sensitive equipment for use in the manufacturing process of silicon wafers. Plants require a “vibration free” environment. Suspended, structured floors can be steel framed or cast in place concrete. Process (clean room) structured floor areas may be designed as much as 10 times stiffer than commercial office floors. Commercial, office structures are designed with natural frequencies in the 5-8 hertz (hz) range (depending on assumed damping). Wafer fab facility process floors can require natural frequencies on the order of 50 hz. The design goal is to eliminate ambient vibrations or “noise” from foot traffic and surrounding rotary machinery.

The process floor structure, in some cases, may be physically isolated from the balance of the building superstructure. This requires a completely separate structural system resisting gravity and lateral loads.

A floor systems’ vibration characteristics can be measured by comparing the calculated beam stiffness frequency product, kf (or f/(), to a known constant. The results of instrumentation of existing office floors to measure vibration levels can provide a basis for comparison. Instrumented commercial office floor systems with kf products of 350-500, velocities of up to 16,000 microinches per second, and moderate damping appear to perform well with limited perceptible vibration. This is easily obtainable with a 30x30 typical office building grid using composite framing with normal weight concrete topping. Vibration perception is limited by: damping, structure mass, and beam span.

Microelectronics facilities can require kf products as high as 64,000. This equates to a structure velocity as low as 125 microinches per second (dB). This extremely stiff structural frame is typically designed as a concrete waffle slab or waffle grid (without a slab). To create this same type of system using structural steel framing would require a heavy composite slab, on the order of 3 inch deck with a minimum 3½” normal weight topping, and stiff beams with short spans. Using well known equations for beam stiffness and frequency a beam’s natural frequency and deflection can be determined. It has been suggested that an appropriate amplitude (deflection) be calculated using a point load midspan of a simply supported beam, accounting for partial fixity from end connections. A structural framing grid of W21 or W24 beams at 8 feet on center (or less) spanning sixteen feet would be required to come close to matching the stiffness of a concrete waffle grid, depending on the cracked moment of inertia used in design. In some microelectronics facilities air flow is required through the process floor. Large openings between beams will reduce the structure mass and damping characteristics. This needs to be carefully considered when designing composite beams to support heavy design live loads and assigning a transformed moment of inertia for beam stiffness calculations.

This article is adapted from a paper to be presented at the National Steel Construction Conference. Nathan T. Charlton, P.E. is an associate and senior project manager with KPFF Consulting Engineers in Portland, Oregon. KPFF is a structural/civil engineering firm with offices in Portland, Seattle, San Francisco, Los Angeles, San Diego and Phoenix. Charlton has a bachelor of science degree in civil engineering and a masters of science degree in structural engineering from Portland State University in Portland, Oregon. He is a registered professional engineer in Oregon, Washington, Idaho, and California.