the steel core to the column's axial strength, but otherwise the beneficial effect of the core is neglected insofar as tie and hoop detailing is considered. Moreover, since the NEHRP composite provisions are new and as yet untried, the practicality of implementing the tie and hoop requirements in practice has not yet been fully demonstrated.

Composite Filled Columns: Many of the same comments regarding the basic strength design criteria in AISC-LRFD and ACI-318 for encased composite columns can be made for filled composite columns. Both specifications include design criteria for filled columns, but as with encased columns there are fairly significant differences between the strengths they predict. Moreover, the same comments regarding the need for shear strength provisions and consideration of limits on material strengths apply to filled columns. The following are areas where additional guidance and clarification is warranted:

- Neither AISC-LRFD or ACI-318 make any mention of the use or need for shear studs placed on the inside of large tube or pipe columns to assist in load transfer between the elements or to inhibit local buckling of the steel cover.

- ACI-318 specifies the same maximum width/thickness ratios as AISC-LRFD which impose a fairly large minimum ratio of the steel area to the gross column area. For example, for steel with a yield strength of 350 MPa (50 ksi), the width/thickness limits impose minimum steel area ratios of roughly 9% and 6% for rectangular tube and pipe columns, respectively. For large columns where there are alternate methods of stiffening the steel plates (for example, by attaching shear studs inside the tube), these limits seem overly restrictive. Moreover, the limits could be relaxed for cases where one does not count on the full axial strength of the steel encasement, and instead only relies upon its role in providing confinement to the concrete.

- The design criteria in ACI-318 do not allow for any increase in effective strength of the concrete in filled tubes or pipes that is more highly confined that concrete in reinforced concrete or concrete encased columns.

- Neither AISC-LRFD nor ACI-318 address constructability issues such as detailing of interior stiffener plates, techniques for placement of concrete, splicing of the steel tubes, etc.

RC Shear Walls with Composite Boundary Members: In buildings combining steel frames with concrete shear walls, it is not uncommon for the boundary member of the wall to consist of an encased composite column as shown in Fig. 4. Whether or not this type of construction is covered by ACI-318 is not entirely clear, however, there are no statements in the specification to suggest that composite columns cannot be used as boundary members. This being the case, the following is a summary of issues regarding the detailing of the composite boundary members that should be addressed in ACI-318:

• What requirements should be imposed for shear studs or other mechanical anchorage devices to transfer forces into the encased steel shape member.

• Should additional wall reinforcement be added at the interface of the wall and the encased column to minimize cracking due to the large relative stiffness difference between the concrete wall and the composite boundary member.

Provisions related to these two items are, in fact, addressed by the NEHRP criteria for composite wall systems and could serve as a starting point for developing criteria to include in ACI-318.

RC Walls with Steel Coupling Beams: At least two recent research projects have been conducted to investigate the design and behavior of steel beams used to couple adjacent reinforced concrete walls (Shahrooz et al. 1993, Harries et al. 1993). Steel coupling beams are sometimes preferred over reinforced concrete beams (1) for RC shear walls used in steel framed buildings, and/or (2) to avoid problems with congestion of reinforcement or RC link beams -- particularly in high seismic regions. Based on the research noted above, recommended seismic design provisions for such beams are included in the 1994 NEHRP. These provisions reference appropriate requirements from AISC-LRFD and the AISC Seismic Specification to design the steel beams, and they point out the need for careful detailing of the beam-wall connection. While the NEHRP provisions are intended to address only seismic issues, some of the recommended design criteria and concepts are equally applicable for non-seismic design and might be incorporated as such into a basic specification or standard.

RC Infill Walls in Steel Frames: Concrete infill walls are another type of construction that has been used as an alternate method for providing increased lateral resistance for steel frames. However, due to the unique nature of this construction, one cannot assume it is intended to be covered by the current ACI-318 criteria for walls. Whether requirements for such systems should be codified in either ACI-318 or the AISC specifications is not clear since the system analysis and design issues are highly dependent on the composite action between the infill and the steel frame. Moreover, while such systems have been used, to the authors' knowledge, there has not any systematic testing of such systems. Nevertheless, it would be desirable to develop guidelines based on existing tests of concrete or masonry infill walls and design practice that would address the following items:

• Criteria for providing force transfer and anchorage between the infill wall and the steel frame.

• Reinforcing requirements for the infill wall.

- Guidelines for the analysis of forces in the infill, frame members, connections, and foundations.

- Special design and detailing requirements for the steel frame to provide ductility under seismic loads.

Encased Steel Plate Shear Walls: As shown in Fig. 5, steel plates encased on one or both sides by reinforced concrete have been used in combination with steel framed structures to resist large shear forces. When lateral forces are very large, such as in high-rise buildings or in very high seismic zones, the steel plates can offer a decided space savings over conventional reinforced concrete shear walls that might otherwise be prohibitively thick. Consider for example that the shear yielding strength of a 10 mm thick steel plate is roughly equivalent to the shear strength of a reinforced concrete wall over 1.5 meters thick. Given the large difference in relative strengths, the concrete encasement is usually not included in the strength calculations, except insofar as it provide as an economical way to stiffen the plate against out-of-plane buckling and to provide fire protection. The NEHRP Provisions include basic criteria to provide a calculate the composite wall shear strength along with basic requirements for connecting the plate to the steel boundary members. There is clearly room for further research on the basic behavior of composite steel plate walls including study of the following issues:

- What are the requirements for minimum thickness and reinforcement of the concrete wall to keep it intact and maintain stability of the steel plate under the anticipated loading shear deformation of the wall?

- What are the requirements for shear studs or other mechanical connectors between the plate and concrete for walls with single or double sided encasement?

- How do openings in the composite wall affect its performance, and how should the openings be detailed.

COMPOSITE CONNECTIONS

Proper design and detailing of connections is perhaps the most critical aspect of many composite systems because (1) the connection details tend to be less standardized than those used for conventional steel or reinforced concrete construction, (2) care must be taken to consider the large difference in relative strengths and stiffness of steel and concrete connection elements to ensure reliable force transfer, and (3) careful detailing is needed to insure constructability of the structures including fabrication, erection, and placement of concrete. Given these concerns, connection design and detailing is an area where the most guidance is needed, but due to the variety of possible details, connection detailing is also an area that is most difficult to codify. Moreover, attempts to codify details often tend to be prejudiced to certain types of systems and connections that can stifle creativity and discourage careful thought by the designer. The danger in over-codifying details is clearly apparent in the wake of the damage to steel moment frames in Northridge earthquake where, prior to the earthquake building design and connection detailing seems to have been dictated more by adhering to the letter of the UBC design provisions than by exercising independent engineering judgment.

Shown in Figs. 6a and 6b are a range of connection types that might be found in the composite systems defined earlier. The connections are distinguished between those that are primarily moment connections versus bracing (axial force) connections. Neither the ACI-318 or AISC specifications currently give any guidance or mention toward the design such connections. The NEHRP Provisions do provide some information, although for the reasons stated above, the NEHRP criteria is mostly limited to qualitative, performance-type provisions.

One example of what may be an appropriate course to follow with regard to connection design is an ASCE committee report on moment connections between steel beams and composite columns (ASCE 1994). This report is based on fairly extensive research in both the US and Japan, and it includes very specific criteria for calculating the connection strength and detailing the reinforcement. It's format was in fact styled after the ACI-ASCE Committee 352 report on reinforced concrete joints (ACI-ASCE 1985). Aside from the mere length of the ASCE report (27 journal pages), the fact that it is very specific to one type of connection probably makes it inappropriate to consider including in a specification such as AISC-LRFD or ACI-318. The same committee of ASCE is currently preparing another report with design recommendations for composite partially restrained connections between composite beams and steel columns. If such reports prove useful to the profession, the challenge will be to maintain these reports as "living documents" that are periodically updated and republished - perhaps in a fashion similar to committee reports in the ACI Code of Practice. However, this is not an easy task, given the volunteer nature and ad-hoc makeup of the committees that generally prepare such reports.

Another source with some guidance for detailing of composite connections is the PCI Design Handbook (PCI 1992). While not targeted for composite steel-concrete structures, this handbook nevertheless provides valuable information related to certain steel-concrete connections. And, it offers another possible model for how information on connections might be collected and disseminated. Besides the committee documents noted above, there are numerous research papers and a few books that provide information on the design of composite connections. However, unless individually authored papers are followed up by incorporation into more authoritative committee reports, generally the guidelines proposed in the papers do not find widespread application in design practice. It is the authors' view that the review and active participation of a committee that accompanies a consensus based approval process will usually produce superior guidelines and requirements than those authored individually. However, this process does require that considerable individual work be completed and available to the committee ahead of time, and that the committee members are committed to the effort. In this spirit, it will continue to be desirable for technical committees of AISC, ACI, ASCE and other organizations to develop design guidelines and standards for connections as supporting information and research becomes available. To the extent that the interest and participants of various technical committees overlap, it would often be advisable to have joint committee efforts.

Besides those instances where design guidelines are currently available, the authors would suggest that there is sufficient need for and information available to support the development of guidelines in the following areas related to connection design:

- Shear Studs - While shear studs are applied in many different applications for composite members and connections, design information for studs is rather fragmented and is often applied out of context. For example, the shear stud strengths provided in AISC-LRFD that were based largely on composite beam tests are often applied to other applications where the local deformations, force transfer, and failure mechanisms are quite different. Information on studs used for embedment plates in precast construction is also available in the PCI Design Manual (1992), the reinforced concrete chapter of the 1994 NEHRP Provisions, and in manufacturers' catalogs. It would be desirable to establish a single resource document on the design and behavior of shear studs and other mechanical anchors that feature a full range of common applications where studs are subjected to tensile and/or shear forces under monotonic and/or cyclic loading.

- Steel Column Base Connections - While typically considered a "steel connection" detail, connections between steel columns and the supporting concrete footings are based on composite action. Moreover, recent experiences in the Northridge and Kobe earthquakes suggest that standard steel base plate details - particularly where the intent is to provide full base fixity - need improvement with regard to anchor bolt design and detailing. Thus, more guidance on this could be provided in either ACI-318 or AISC-LRFD, or a separate design standard.

SUMMARY AND CONCLUSIONS

As outlined in this paper, while some design provisions for composite members are generally available in existing specifications and standards, there is considerable room for improvement to fill in gaps and to better coordinate the existing criteria. Moreover, there are important topics related to criteria for structural system behavior and connection design that are currently not available. Recent developments of provisions for composite structures generated through ASCE and BSSC (NEHRP) demonstrate that progress is being made to incorporate recent research results into practice. The AISC seismic and composite subcommittees (TG 106 and TG 107) have begun taking steps to improve the AISC specifications by considering the adoption of the NEHRP Provisions into the AISC Seismic Specification and making other improvements to the basic AISC-LRFD Specification. It is hoped that such efforts continue and be extended to include coordination with ACI through the revitalization of ACI Committee 340 on composite construction.

The following is a brief summary of major areas where the authors think considerable progress could be made in the short term through a coordinated effort between the technical committees of the organizations involved:

- Composite Columns - Improve and make more consistent the criteria for encased and filled concrete columns in the ACI-318 Code and AISC-LRFD Specifications.

- Composite Beams and Trusses - Improve the provisions currently in the AISC-LRFD Specification through coordination with the ASCE committee reports and standards.

- Seismic Design - Provide coverage for the seismic design of composite structures in the load provisions of ASCE-7, and the structural design provisions of the ACI-318 Code and AISC-LRFD and AISC Seismic Specifications. While many of the suggested criteria are currently available in the 1994 NEHRP Provisions, these need to be adopted by a standard or specification that can be referenced by building codes.

- Composite Connections - Continue the trend of developing specialized design guidelines for specific types of composite connections. This is an effort that is probably best handled through technical committee reports and papers outside the realm of mandatory design criteria in specifications.

Beyond these efforts which are rather limited in scope, there continues to be the need to conduct research to provide behavioral information to develop improved design guidelines for new composite systems, members, connections. In addition, there is considerable room for expanding the scope of design criteria beyond minimal requirements for strength to include more guidance on calculating structural response for both serviceability and strength limit states.

Finally, the authors cannot overemphasize the point that greater effort needs to be taken to improve coordination between the organizations and technical committees preparing guidelines, specifications, and standards for composite construction. In certain instances, new stand-alone standards and guidelines are appropriate, but these should prepared in general accordance with existing specifications. Moreover, these supplemental standards cannot take the place of coordinated and well thought out provisions for composite construction in the basic AISC-LRFD Specification and ACI-318 Code.

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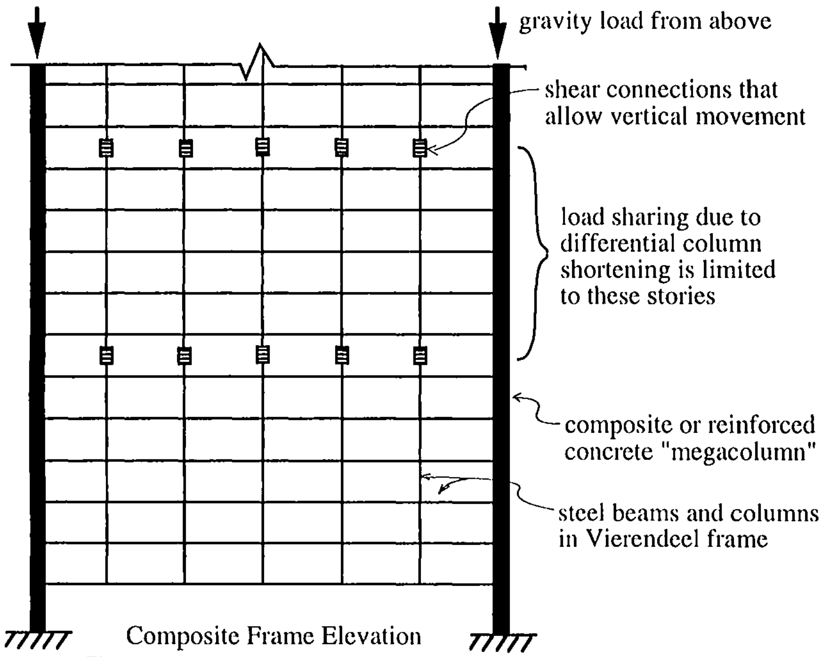


Fig. 1a—Composite Vierendeel Frame

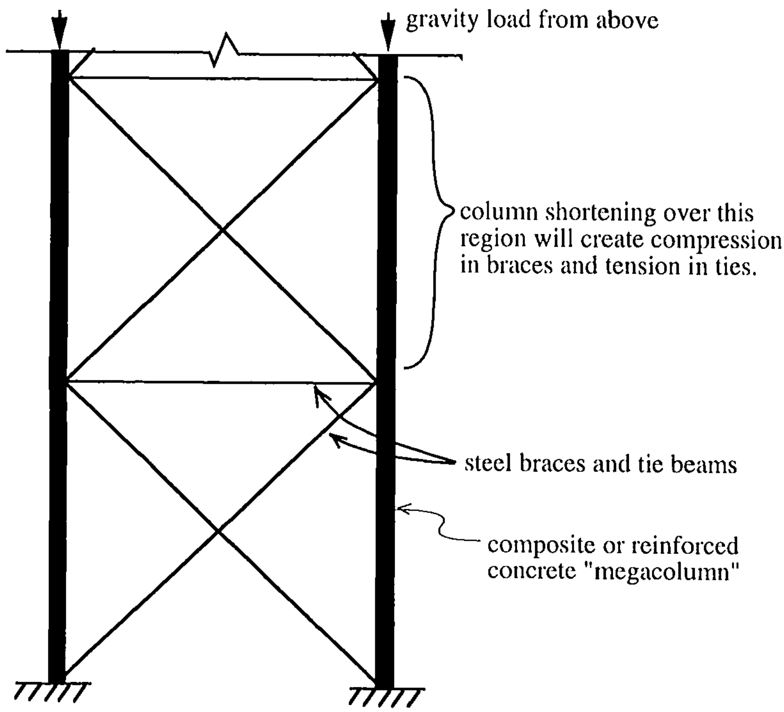
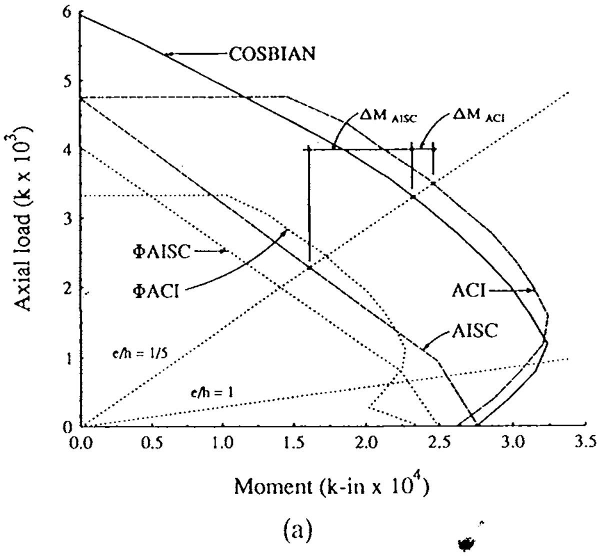


Fig. 1b—Composite Braced Frame



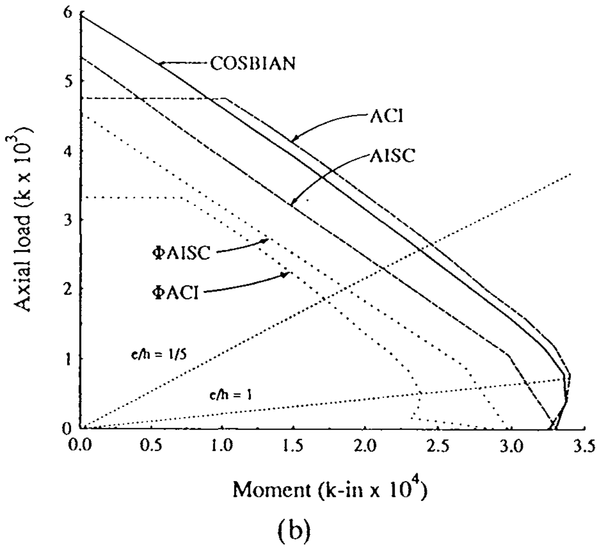


Fig. 2—Nominal and Design Strengths for Encased Composite Column (a) Uniaxial Bending (b) Biaxial Bending (El-Tawil et al. 1995)