CONCLUSION

I have tried to summarize the various ways we strengthen buildings with concrete for improved seismic performance. The most common and probably the best system is to add new reinforced concrete shear walls. It makes a building much more rigid, reduces seismic drifts or deformations and thus reduces damage and prevents the potential of collapse.

I chose this topic perhaps a year and a half ago when I was asked to give this talk at this symposium honoring Mike Uzuemeri. I am deeply honored to be asked and be able to participate in celebrating Mike's career here in Toronto. When I chose the topic, little did I know that an August 1999 earthquake would occur in Mike's homeland of Turkey with many concrete buildings collapsing, causing a great loss of life. I am writing this paper in May 2000 having just returned from a World Bank workshop in Ankara advising on how to strengthen the damaged buildings that did not collapse but have been vacated for safety considerations. I felt it was very presumptuous of me, an engineer from California, to go to Turkey and tell Turkish engineers how to strengthen their buildings. So, I put aside my engineering credentials and spoke as a salesman, since salesmen can be pushy and aggressive. I was a salesman selling shear walls or structural walls and I hope I was effective. Most agreed that if the Turkish buildings had more shear walls that performance would be markedly improved.

So today, I honor the career of Mike Uzuemeri and his contributions to our knowledge of reinforced concrete structures and how they perform in earthquakes. The vulnerability of concrete buildings in the earthquake prone regions of the world is extensive, as evidenced by the recent Turkish event. Adding new shear walls or infilled walls to these buildings is extremely effective, and I hope the motivation and funding becomes available to implement these suggestions and to reduce this potential for devastation and loss of life throughout the world.

A Link Between Research and Practice: ACI 352 Recommendations for Design of Joints in RC Structures

by J. O. Jirsa

Synopsis: The mission of most ACI technical committees is to "develop and report information" and a large number of missions include "develop and maintain standards" for use in design, construction, maintenance or other practice-related application. In general, the reports technical committees develop become prime sources of information in their assigned area. The objective of this paper is to document the formation of the committee and the development of the first report of ACI 352 "Joints and Connections in Monolithic Concrete Structures" published in 1976. The reports of ACI 352 have had considerable impact on the design and construction of concrete structures. The activities of ACI 352 provide a case study in the role of a committee in providing a vital link between research and practice. It seemed appropriate to discuss the work of ACI 352 at the Uzumeri Syposium because Mike Uzumeri served as a member of the committee. His research on the behavior of beam-column joints was an important part of the data on which the first report of ACI 352 was based.

Keywords: codes; construction; design; joints and connections; practice; reinforced concrete; research

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INTRODUCTION

In 1960, Siess (1) published a paper entitled "Research, Building Codes, and Engineering Practice." In that paper he stated, "The practice of engineering as a profession is, by its very nature, based on knowledge. There are basically only two sources of this knowledge: research and experience." In order for an engineer to advance his knowledge beyond that which was current at the time of his/her formal education, it will be necessary to "keep on learning." While this can be done on an individual basis, it may be more efficient to do this collectively. Associations of people in any field are formed for this purpose and ACI is no different. In fact, the value of most technical societies is that they provide a forum for such collective activity and they support, maintain and encourage participation. Siess outlined the process by which committees "study collectively the results of research and current practices" and use their "collective judgement" to prepare "a summary of existing knowledge." Although Siess discussed the process as it related to code development, the same statements apply to other technical documents.

For many committees, it seems that the only validation of their work that is acceptable is the inclusion of their "knowledge" in a code or standard. The success of a committee in developing knowledge should not be judged in this way. The objective of this paper is to provide a case study of a committee document that was widely used in practice for many years before any of its recommendations were incorporated into a code or standard.

The Committee Process

Figure 1 is from the paper by Siess and represents the complex interactions between research, codes, and practice. The interactions are as valid today as they were 40 years ago—little has changed even though the flow of information is much faster with today's technology. The process of discussing research results and tempering them with the experience gained in practice is a very human process that has not yet been computerized. Although today's information technology makes participation in committee work possible through electronic means, it cannot replace the camaraderie of face-to-face discussions and social interactions that occur at meetings. These are features of committee and association activity that must be retained.

One of the benefits of committee participation is the exposure to diverse opinions--often expressed very forcefully. ACI has always followed a rigorous consensus process for developing codes, standards, and technical documents. Consensus is not unanimity, but it is a process by which general agreement can be reached on an issue, that is, a position is reached that all involved can live with. Compromises are made and different points of view are heard and respected.

There are indications that associations are having difficulty in recruiting new members and volunteers, and in retaining current members. Volunteers must find value in committee membership. Generally, value is found in the opportunities for continued learning and professional growth that committee work provides. Furthermore, volunteering must be enjoyable. Certainly, interaction with others having like interests is a key element; but developing long term friendships and gaining an understanding of the spirit of cooperation, mutual respect, and compromise are important benefits.

Time from Research to Practice

"One of the greatest ills of the engineering profession is the long lag between research and practice—the time elapsing between the discoveries and findings of research and their general acceptance and application by engineering practitioners." This familiar criticism is a quote from the first lines of a paper by Sheets (2) that was delivered in 1938 at the 34th Annual Dinner of the American Concrete Institute. He makes a "frank analysis of the existing situation" by examining the sort of people who make up the practitioner and research groups. The "manner of men" who make up the practitioner group (in 1938 all practitioners were men) include:

- Executives who are too busy to study research but have the ability to do so.
- Executives who are non-scientific, impatient, and "given to direct action."
- Close-minded individuals who know everything and "pooh-pooh" any new proposal.
- Engineers who "scoff" at any problem that cannot be solved with arithmetic and simple equations.
- Know-it-alls.
- Those who belong to "do-it-the-way-we-learned-in-school crowd."
- Those who belong to the "copy-cat, tradition-loving, mentally lazy flock."
- A very few who are "just plain dumb."
- Engineers who are "smart, open-minded searchers" for improving their knowledge.

The research group includes:

- "Inhabitants of the technical stratosphere" who are unable or unwilling to express themselves using the "language" of the practitioner.
- "Cloud riders" who are not as abstract as the "stratospherists" but are not understandable to the practitioner.
- "Technical adventurers" who conduct research without assuming any responsibility for interpreting or completing their studies.

- A few technical "snobs" who "like to talk a ten cent idea in ten dollar language."
- Self-advertisers who use research as a ladder to their own success rather than as contributors to a profession.
- The "conscientious thinkers, unselfish servers of fellow engineers, and the rare species that can think deeply, conclude soundly, and talk simply."

Sheets discusses the characteristics of a good research report and the need for an "interpreter" to fill the gap between research and practice. Although there are individuals who have such capabilities, for example textbook authors, he suggests that a joint committee of researchers and practitioners could be an "interpreter." Obviously, the people described last in each of Sheets' groups are the ones who would constitute the ideal committee for filling the gap. Through the collective judgement of a committee with diverse membership, the time required to convert research results to information that can be implemented by practitioners will be reduced.

Siess (1) also comments on the lag between research and practice and cites several cases where the findings of research projects did not change codes or practice for 30 years or more. It must be remembered that the prime role of codes is to provide public safety. Therefore, code-writers tend to be conservative in applying research findings and they wait until there is verification by other researchers or the body of knowledge is sufficient to permit extrapolation to a variety of cases. Such long lags are frustrating and discouraging to researchers, however, codes are not the only avenue for implementation of findings. Well-written reports and papers on topics of interest that address critical issues in design and construction may have just as large an impact as code provisions. The work of ACI 352 is an example of a report that had significant impact on design well before some of the provisions were incorporated into the ACI Building Code (3).

ORGANIZATION OF ACI 352

The Joint American Concrete Institute-American Society of Civil Engineers Committee on Joints and Connections in Monolithic Structures (ACI 352) was official organized in 1966. The first meeting of the committee was held in October 1967 at the ACI Convention in Des Moines, Iowa. Prof. Mete Sozen was appointed to chair the committee. The mission was: "*Study the detailed design of joints and connections in monolithic concrete members and develop practical aids for the designer and the constructor.*" The roster of members in 1967 and 1976 are shown in Appendix A. The mission and the membership was selected to address what was considered to be a gap in the design and construction of monolithic concrete structures—the joints between elements. Prestressed and precast structures were considered to be outside the scope of the committee.

Des Moines, October 1967--The discussion at the first meeting (4) was of a general and probing nature to attempt to define the problem the committee faced. The need for defining categories or classifying joints was discussed. There [...] d—beam to column and slab to column joints. There was disagreement as to the need to consider seismic and non-seismic loading as separate cases. Reese who had been a proponent for the organization of the committee suggested that the goal of the committee should be to help the designer create a good joint, and that while complex problems need to be studied, there were no rules or guides existing for even simple beam-column joints. He stated that there was a need for standard joint specifications to eliminate joints being designed by detailers rather than by engineers but it was not clear whether these should be in the form of standard details or guides for good design. Several members agreed to submit some typical joint details. The members were asked to submit references about joint failures and Sozen asked the members to consider the course of action to be taken.

Immediately after that meeting, Reese sent a letter (5) to the members in response to questions that had arisen in the discussion in Des Moines. His letter is a masterpiece in which his years of experience in joint design were evident but so was his frustration with the state of the art. First he asked, "What is being done now?" and then posed a series of questions that defined the state of joint design as follows:

1. Detailed design of joints was being left to reinforcing bar detailers.
2. Design drawings usually cover (joints) with a few notes such as "Follow ACI 315" or "Comply with all of ACI 318."
3. Seldom are even a few typical details provided.
4. Technical high school graduates and self-trained draftsmen have replaced graduate civil engineers as detailers.
5. Detailers cannot "design" a joint because they do not know the forces involved or the type of building and its intended use. They must rely almost exclusively on manuals and handbooks.
6. Computer detailing will make the mechanization of joint design even more desirable.
7. Typical joints are sufficiently alike that careful study and standardization is possible and desirable.
8. It may be possible to categorize joints by the forces they will need to withstand.
9. A review of the state of affairs in joint detailing clearly establishes the need for the committee to act.

Reese asked "Is it not short-sighted, and possibly dangerous, to spend so much time in making involved frame analyses and pursuing sophisticated methods which are directed almost entirely to the main members, and leave the joints and connections to detailers?" After considering various options, he advised the committee to develop "a manual covering joints only in all phases from routine to complex, making all material available under one cover and not enlarging other manuals, which are already large enough." He further asked if "people will use the material when it is completed?" and answered that "If it comes out in final form as usable as the Detailing Manual, the Design Handbooks, and similar aids, it will not only be used but will be a best seller." Reese suggested two approaches that might be considered: (a) Show by discussion and illustration how joints should be designed, and (b) for a group of typical joints, provide requirements that are "more in geometric than stress terms" that detailers can use. He thought it was unlikely that there was sufficient research to prepare such a document but that the committee could also suggest research that would broaden the knowledge base.

The remainder of his letter identifies various groupings of typical joints and lists problems and questions about each group. Reese's letter set the course of the committee for the next eight years when the first report was published. Many of his questions remain unanswered today. His insight and his ability to pose the right questions were key factors in directing the committee to developing a document that would influence design and construction of reinforced concrete structures.

Los Angeles, March 1968—Problems in joint construction were discussed by the practitioner members of the committee. Broyles and Black described current detailing practices. Congestion problems were often not solved until the steel was placed in the field. Details were not checked by designers for congestion of bars and for ease of placement. The committee discussed a variety of issues related to beam-column joints. Pinkham suggested that beam-column connections probably were the most general case and the simplest to consider is a joint where the beams and columns are approximately the same size or where the beam is slightly smaller than the column so that the beam bars fit inside the column bars. Degenkolb suggested that the connection should develop the strength of the members and should be ductile enough to "hang together" under the applied forces or deformations. Various ideas for "keeping failures out of connections and in the members" were discussed.

The committee assembled a number of reports from the literature on failures in which some aspect of joint design or construction was involved (6-10).

DEVELOPMENT OF REPORT

Following the Los Angeles meeting a draft outline of "Requirements for Beam-Column Joints" was prepared by a subcommittee for discussion by the entire committee. By attempting to set specific, sometimes quantitative, requirements for beam-column joint design, various concerns and suggestions for changes were elicited from the committee members. Four joint cases and the primary design criterion for each case were proposed:

1: Strength
2: Energy absorption and strength (blast loading, for example)
3: Limited ductility and strength (ordinary joint, ultimate strength design)
4. Resistance to several repetitions of overload with plastic deformations developed (structure in a high seismic zone)

A key element of that first draft was the requirement that the joint must be designed to develop specified levels of steel strains (given as a multiple of yield strain) for each type without impairing its ability to transfer or resist the forces acting on the joint. The stresses in the bars (or forces acting on the joint) had to be consistent with the strains. The intent was to require consideration of strain hardening when large deformations were expected in the members at the joint. Where ductility is required, a "Curvature multiplier" was defined.

A Case 1 joint should have sufficient strength so that the strength of the members is developed before the joint reaches its capacity. A cantilever beam framing into a column is an example of such a case. Ductility is not a concern. For Case 2, energy absorption during large deformations under unidirectional overloading was of prime concern. Overloads due to blast or wind loading were considered to produce such deformations. For Case 3, a joint in a frame designed using ultimate strength design principles was envisioned. In order to develop the strength of all the elements, some moment redistribution is needed. The elements framing into a joint must undergo inelastic deformation for redistribution to occur. For Case 3 joints, some minimum level of ductility is needed and the joint strength must be maintained as the inelastic deformations are developed. In Case 3 joints, the strains are not expected to go into the strain hardening range. However, Case 4 joints were expected to develop a rotation capacity of five times that corresponding to first yield for at least five load/deformation oscillations (load reversals). The details had to be such that the strength of the joint did not fall below 75 per cent of the first cycle strength. The focus of Case 4 was frame structures located in zones of high seismicity.

Since there was little test data available regarding joint response, the strength of the joint was determined using shear and bond values from ACI 318.

Memphis, Nov. 1968—During this meeting, many issues regarding the document for beam-column joints were clarified as the draft outline was discussed. It was agreed that detailing to avoid congestion was a critical issue and that design of joints should be considered to include detailing. There was disagreement as to how much of the structure would be considered part of the joint. Many felt that parts of the members framing into the joint should be included while others argued that if large segments of the members are included, the whole structure could be considered joint design! A major point was the decision that the joint must be designed for the capacities of the members framing into the joint and not only to develop the design forces. The idea of a multiplier on reinforcement stresses to replace a strain multiplier was proposed.

Jennings discussed the problem of specifying required ductility and load reversals for joints. He used an example to illustrate that local or joint ductility could be considerably greater than overall frame ductility. Using measured accelerograph records of a reinforced concrete building from the 1964 Niigata earthquake, he showed that number of plastic excursions were fewer than the number of cycles of alternating load. He indicated that the proposed requirement of 5 times yield deformation for 5 reversals seemed reasonable for Case 4 joints.

Subsequent Meetings and Discussions—Work on the report on beam-column joint design was completed in 1975 and it was published in the July 1976 ACI Journal (11). Many meetings were devoted to reaching agreement on various parts of the report. At one point, there was concern that the report was becoming too "academic." However, these concerns were addressed through the development of illustrated design examples. The number of joint cases was eventually reduced to two—Cases 1-3 were considered to be covered by a Type 1

Joint and Case 4 became a Type 2 Joint. A stress multiplier was introduced using the results of tests in which strains were measured in hinging regions of beams. For Type 1, strains were not expected to reach strain hardening so the stress multiplier was 1.0. After considering a range of stress multipliers for Type 2 from 1.1 to more than 2, the committee adopted a value of 1.25 for joints where large deformations and deformation reversals into the inelastic range were expected.

Finally, it was decided that the joint included only "the portion of the column within the depth of the beams framing into the column" as shown in Fig. 2. The recommendations were limited to joints where the column width was equal to or greater than the beam width. Perhaps the most contentious aspect of the report was the calculation of the shear strength and the requirements for transverse reinforcement within the joint. The common practice was to terminate the column transverse reinforcement above and below the joint (or floor members). There was concern that the addition of joint transverse reinforcement would raise costs and affect the competitiveness of concrete construction. The committee decided that it would present the "Recommendations" in a format similar to that used in the Building Code. In this way, an explanation of the requirements would be immediately available to the user.

THE 1976 REPORT

The abstract indicated, "*The recommendations are based on laboratory as well as field experience and provide a state-of-the-art summary of current information. Areas for needed research are identified. Design examples are presented to illustrate the use of the design recommendations.*" The format of the report was as follows:

- Recommendations:
  - Introduction
  - Classification of beam-column joints
  - Design considerations
    - Forces
    - Critical Sections
  - Requirements for joints
    - Serviceability
    - Strength
- Areas of needed research
- Design Examples

Recommendations

Joint classification--The report identified the differences between joints in structures where strength was the prime concern (Type 1) and those where large inelastic, cyclic deformations were expected (Type 2). Where large inelastic deformations were imposed on the members, the joint had to be designed to withstand the increases in bar stresses that would occur under strain hardening.

Tests (12) showed that strains at the face of a support, where the member was hinging, would pass through the yield plateau very quickly as shown in Fig. 3. It was also shown analytically that such increases would be expected where there was a moment gradient in the member at the face of the column. As a result, the bars would be stressed beyond yield and a stress multiplier of 1.25 was to be used to determine shear forces in the joint and for anchorage of bars in or through the joint. The transfer of forces from the members to the joint was shown to produce diagonal cracking similar to that observed in the field.

Shear and transverse reinforcement--Although there were suggestions that the shear capacity of the concrete in the joint should be taken as zero for a Type 2 joint, the committee decided that there was insufficient data to warrant such a recommendation. Transverse reinforcement was needed to provide whatever shear could not carried by the concrete.

In addition, there were minimum area and spacing requirements for the transverse reinforcement. The need for a "basket" to contain the joint core was established. Because joints often had members framing in from more than two directions, designers implicitly considered the joint to be confined without considering the size of those members or the efficiency of beams and columns in confining the joint. A review of joint failures under earthquake loading indicated that for transverse reinforcement to be effective, the hook extension needed to be anchored into the confined core of the joint. The geometry of the transverse reinforcement was described so that designers understood the need to provide 135° hooks to properly confine the joint core in Type 2 joints. Further, crossties were to be bent around peripheral ties (a requirement that was changed in later reports because it was difficult to achieve in the field and there was no evidence that indicated such cross-ties substantially improved confinement).

Column/beam strength--The flexural capacity of the columns was required to be greater than the capacity of the beams framing into the joint. In Type 2 joints, the beam capacity had to be determined using the stress multiplier.

Hooked bar anchorage--Finally, the provisions for anchorage of hooked bars in the joint required a straight bar anchorage length needed to make up the difference between the hook capacity and the expected bar stress at the critical section defined at the face of the core (column bars or ties). The straight bar length could not be added to the tail extension as was the practice in many cases. This provision was included so that designers or detailers would not use large hooked bars in small columns or walls.

Needed Research

Perhaps the most important aspect of the report was the identification of research needs. Eleven areas of research were listed corresponding with those issues where there was found to be inadequate information available for developing the design recommendations and answering some of the questions that had been posed. These areas included effectiveness of confinement, influence of lateral members (including size and location), shear strength of joint (effective area,