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Research

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U.S.-Japan Cooperative Earthquake Research Program
Phase 5 - Composite and Hybrid Structures

SUMMARY, RESOLUTIONS, AND RECOMMENDATIONS OF THE FIFTH JOINT TECHNICAL COORDINATING COMMITTEE MEETING

(Tokyo, October 5-7, 1998)

Edited by

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PREFACE

The five-year research program on Composite and Hybrid Structures as Phase 5 of the U.S.-Japan Cooperative Earthquake Research Program was initiated in 1993 in both countries. The research work in Japan started in fiscal year 1993. However, fuller participation of researchers on both sides started in early summer 1995 when the first year U.S. side research projects were started. The sponsorship of the program is by the National Science Foundation in the U.S. and by the Ministry of Construction along with a number of industry groups in Japan.

Because of diverse and broad scope of the subject area, the research program is organized into the following four groups: Concrete Filled Tube Column Systems (CFT); Reinforced Concrete (RC) and Steel Reinforced Concrete (SRC) Column Systems (RCS); RC / SRC Wall Systems (HWS); and New Materials, Elements and Systems (RFI).

The program objectives are to develop practical analysis and design procedures for structures in the first three groups and feasibility studies of new and innovative structural elements and composite systems in the fourth group. A theme structure with well selected layout, geometry and design loads is used, which provides a common focus for various systems to be studied, and also a common prototype structure from which the components and sub-assemblages are drawn. The research program is following the recommendations of the Joint Planning Group as given in the final report of the Planning Workshop held in Berkeley, CA, September 10-12, 1992. Cooperation (sharing of research data and exchange of personnel) and coordination of work by all participants is an integral part of this program. Active participation of practitioners and various industry representatives in planning, coordination and execution of the research work is also a strong feature. Various committees have been formed for this purpose. A Joint Technical Sub-Committee (JTSC) in each of the four components of the research program provides technical advice and coordination. Each JTSC has a co-chairman from each side with membership including all researchers in that area. These groups meet as often as needed. All participants and institutions are also part of the overall Joint Technical Coordinating Committee (JTCC) to review progress and discuss scientific and technical issues on a common basis. This committee meets once a year. The first JTCC meeting was held in Tsukuba in November 1993, the second in Hawaii in June 1995, the third in Hong Kong in December 1996, and the fourth in Monterey, California, in October 1997. A smaller group called Joint Steering Committee (JSC), which consists of key representatives from the JTCC, oversees the program and provides guidance on issues that are common to the four components. The overall program has a technical coordinator and a co-chairman from each side.

This volume contains proceedings of the 5th JTCC Meeting - research summaries, resolutions and recommendations. It is anticipated that a couple more meetings will be held in the coming years prior to the successful completion of the program.

FINAL PROGRAM

U.S.-Japan Cooperative Earthquake Research Program
Phase 5 - Composite and Hybrid Structures

Fifth Joint Technical Coordinating Committee Meeting (5th JTCC)
October 5-7, 1998
Tekko Kaikan
3-2-10, Kayaba-cho, Nihonbashi, Chuo-ku, Tokyo 103-0025, JAPAN

Monday, October 5 (Room number 701)

Introduction Chairmen: Aoyama / Goel

9:00	Welcome (Aoyama, Goel)
	Meeting Schedule / Objectives (Yamanouchi, Goel)

Summary Session Chairmen: Aoyama / Goel

9:30 - 10:00	CFT Research Program (Roeder / Morino)
10:00 - 10:30	RCS Research Program (Deierlein / Noguchi)
10:30 - 11:00	Coffee Break
11:00 - 11:30	HWS Research Program (Wallace / Wada)
11:30 - 12:00	RFI Research Program (Goel / Tanaka)
12:00 - 13.30	Lunch
13:30 - 18:00	Parallel Joint Technical Subcommittee (JTSC) Sessions
	Presentation of Progress Papers by Researchers; Discussion
	JTSC 1 - CFT (Room number 802)
	Co-chairmen: Roeder / Morino
	JTSC 2 - RCS (Room number 803)
	Co-chairmen: Deierlein / Noguchi
	JTSC 3 - HWS (Room number 804)
	Co-chairmen: Wallace / Wada
	JTSC 4 - RFI (Room number 605)
	Co-chairmen: Goel / Tanaka
18:00 -	Reception / Dinner (co-hosted by U.S. and Japan sides)

Tuesday, October 6

9:00 - 12:00	Parallel Joint Technical Subcommittee (JTSC) Sessions (Continued)
	Presentation of Progress Papers by Researchers; Discussion
	JTSC 1 - CFT (Room number 802)
	Co-chairmen: Roeder / Morino
	JTSC 2 - RCS (Room number 803)
	Co-chairmen: Deierlein / Noguchi
	JTSC 3 - HWS (Room number 804)
	Co-chairmen: Wallace / Wada
	JTSC 4 - RFI (Room number 605)
	Co-chairmen: Goel / Tanaka
12:00 - 13:30	Lunch
13:30 - 18:00	Parallel Joint Technical Subcommittee (JTSC) Sessions

(Continued)

Discussion and Preparation of Summary Reports
JTSC 1 - CFT (Room number 802)
Co-chairmen: Roeder / Morino
JTSC 2 - RCS (Room number 803)
Co-chairmen: Deierlein / Noguchi
JTSC 3 - HWS (Room number 804)
Co-chairmen: Wallace / Wada
JTSC 4 - RFI (Room number 605)
Co-chairmen: Goel / Tanaka

Wednesday, October 7 (Room number 701)

9:00 - 12:00	Closing Session Chairmen: Aoyama / Goel
9:00 - 10:30	Final JTSC Reports
10:30 - 11:00	Break
11:00 - 11:50	Recommendations, Resolutions
11:50 - 12:00	Closing Remarks
12:00	Adjourn

* Technical tour to construction site of Tokyo Dome Hotel on Wednesday afternoon
** Technical visit to BRI and NIED laboratory in Tsukuba city on Thursday

LIST OF PARTICIPANTS

U.S.-Side

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N. Krstulovic	North Carolina State University
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Y. Kurama	University of Notre Dame
V. Li	University of Michigan
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S. Liu	National Science Foundation

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U.S.-Japan Cooperative Earthquake Research Program
Phase 5 - Composite and Hybrid Structures

SUMMARY, RESOLUTIONS AND RECOMMENDATIONS OF THE FIFTH JOINT TECHNICAL COORDINATING COMMITTEE MEETING

(Tokyo, Japan, October 5 - 7, 1998)

SUMMARY

The Fifth Joint Technical Coordinating Committee (JTCC) Meeting of the U.S.-Japan Cooperative Earthquake Research Program on Composite and Hybrid Structures was held at Tekko Kaikan in Tokyo, Japan, on October 5-7, 1998. Fifteen Japanese and twenty-four U.S. JTCC members, plus thirty-nine observers participated in the meeting.

On the first half day of the JTCC meeting (October 5), the general session was held in which summaries and progress of research work on both sides were presented and reviewed.

During the next one half day (October 5-6), participants were divided into four joint Technical Sub Committees (JTSC's) - JTSC 1 (CFT), JTSC 2 (RCS), JTSC 3 (HWS), and JTSC 4 (RFI). Presentations from individual researchers and discussions in each JTSC session concentrated on reviewing the detailed research results, design guidelines planning for future cooperative work and exchange of information and personnel, and identifying gaps and needs in the current program.

During the plenary session on October 7, reporters from each JTSC summarized the current status of research work design guidelines and plans and recommendations for future work. After the JTSC reports, following Resolutions and Recommendations were adopted.

RESOLUTIONS

1. Members of the JTCC agree that the meeting was successful and fruitful for both countries in a cordial atmosphere in Tokyo, Japan. They further agree that excellent progress has been made in the joint research program.

2. Members of the JTCC re-affirm the recommendations for research, personnel exchange and cooperation as contained in the joint planning group's report, "Recommendations for U.S. - Japan Cooperative Research Program - Phase 5, Composite and Hybrid Structures".

3. Members of the JTCC accept the reports of the JTSC's and acknowledge their fine efforts to develop and coordinate very effective research plans, and to synthesize and interpret the results obtained.

RECOMMENDATIONS

1. Exchange of researchers, and research data (e.g., via www) on both sides should be continued.

2. Close cooperation and collaborative research effort on both sides should be continued till the end of the five year program of both countries.

3. Efforts to synthesize and interpret knowledge gained in the program, to disseminate this knowledge and design/analysis methodologies to the design profession and industry, and their acceptance into relevant codes should be accelerated.

4. Planning effort should be initiated to perform testing work on carefully selected full structural systems in possible cooperation with other research programs.

5. Material manufacturers, construction and other industrial organizations should continue to actively support the research program.

6. Each JTSC should meet as needed to achieve good coherence in the cooperative research work.

7. Each JTSC should continue development of performance criteria as related to design guidelines to be developed in each country.

8. Funding should be provided for joint coordinated publication of research work with practical implications.

9. The 6th JTCC meeting should be held in late summer of 1999 at a place to be hosted by the U.S. side.

U.S.-Japan Cooperative Earthquake Research Program
Phase 5 - Composite and Hybrid Structures

THE FIFTH JOINT TECHNICAL
COORDINATING COMMITTEE MEETING
(Tokyo, Japan, October 5-7, 1998)

Report of the Working Group on Concrete Filled Tube Column System (CFT Technical Sub-Committee, TSC-1)

Sub-Committee Co-chairs:
Prof. S. Morino, Mie University
Prof. C. Roeder, University of Washington

PARTICIPANTS

Japanese Participants:

S. Morino (Co-Chair)
K. Sakino
I. Nishiyama
A. Mukai
K. Yoshioka
E. Inai
T. Fukumoto
S. Gokan
Y. Hayashi
T. Nakamura
T. Fujimoto
H. Sawada
M. Uchikoshi

U.S. Participants:

C. Roeder (Co-Chair)
A. Azizinamini
J. Jirsa
Le-Wu Lu
J. Ricles

See attachment for email addresses and affiliations.

PRESENTATIONS WERE MADE ON RESEARCH PROJECTS

Projects on Japanese Side

1. T. Fujimoto, "Behavior of Beam-to-Column Connection of CFT Column System"
2. T. Nakamura, "Design Example of CFT Structure"
3. M. Uchikoshi, "Trial Design of CFT Theme Structures (1)"
4. Y. Hayashi, "Trial Design of CFT Theme Structures (2)"

Projects on U.S. Side

1. A. Azizinamini, "Development of Design Criteria for Steel Beam to Concrete Filled Tube Column Connections in Seismic Regions"

2. J. Ricles, "Seismic Behavior and Design of Moment connections for CFT Column Systems"

3. J. Jirsa, "Push-Out Behavior of Concrete-Filled Steel Tubes" and "Panel Zone Behavior for Moment Connections Between Concrete Filled Tubes and Steel Beams"

4. C. Roeder, "Stress Transfer Between Steel and Concrete in Composite and Hybrid Construction"

5. J. Ricles, "Seismic Behavior and Design of High Performance Concrete-Filled Steel Tube Columns"

SUMMARY OF PROGRESS - ITEMS IN PROGRESS ARE NOTED AS SUCH

The Japanese testing program is completed while the U.S. program is nearing completion. Japanese work has evolved into development of design guidelines and recommendations. Significant progress during the past year was noted in the specific areas noted below.

1. **CFT Beam to Column Moment Frame Connections**. An extensive test program has been completed in Japan, and an extensive test program is nearly completed in the U.S. Data analysis is under way in both countries, and a number of important observations were made as to the types of connections which are most promising in the two countries and the behavior expected from these connections.

2. **Beam Columns**. Beam column tests are well under way in the U.S. on rectangular CFT members with a wide range of material properties and geometries.

3. **Material Behavior and Fundamental Mechanics**. Significant work on the effect of confinement on the behavior of concrete is nearly complete in Japan. One study is in progress in this area in the U.S. A study on bond stress transfer between steel and concrete has been completed in the U.S. and design recommendations have been developed.

4. **Database development**. In Japan great strides have been made toward developing a summary database of test results. More detailed information is obtainable through discussion with individual researchers.

5. **Design Guidelines**. Design guidelines for all aspects of CFT frame design have been developed in Japan (summaries will be translated to English), but similar work needs to be done in the U.S.

6. **Trial Designs and Economic Evaluation**. Practical evaluations of design guidelines have been completed in Japan. This work has shown that frames with CFT columns can be significantly more economical than steel construction or SRC. Similar work is also needed in the U.S.

MAJOR RESEARCH FINDINGS / ACCOMPLISHMENTS

The U.S. side is lagging behind the Japanese side but significant accomplishments and findings have been made in both countries. These are listed below.

1. Behavior

- Effect of Confined Concrete
- Effect of Local Buckling of Steel Tube
- Deformation Capacity, Energy Dissipation Capacity of Beam-Columns
- Behavior of Moment Frame Connections
- Bond Stress and Shear Transfer Between Steel and Concrete
- Testing with High Strength Materials (in progress)

2. Analysis

- 3-D Stress Distribution of Beam-Columns and Connections - FEM Analysis
- Stress-Strain Relation of Confined Concrete
- Stress-Strain Relation of Locally-Buckling Steel Tube
- Method of Analysis of M-φ Relation
- Method of Analysis of M-R (Q-R) Relation
- Formulas to Evaluate Stiffness, Strength and Deformation Capacity of Beam-Columns
- Modeling of Restoring Force Characteristics

3. Design

- Design of Theme Structures
- Design Formulas for Beam-Columns
- Design Formulas for Connections
- Design Details
- Economical Floor Plan - Number of Columns
- Cost Performance Evaluation
- Construction - (Concrete Mixture, Tests, Casting) Not Presented
- Development of Design Guidelines for Frames with CFT Columns (Japan Only)
- Initiation of Guidelines for Moment Connections and Shear Connector Requirements in U.S.

RECOMMENDATIONS FOR FUTURE WORK / RESEARCH NEEDS

The following are sub-committee recommendations for further work. Items 1, 2 and 3 are highest priority.

1. Braced Frames with CFT Columns. Braced frames may be the best and most economical application of CFT in U.S. practice, because of the large axial stiffness and resistance of CFT. Most existing CFT applications in the U.S. have been braced frames, and the connections in these existing buildings have been expensive with uncertain reliability and behavior. Braced frames and their connections will be quite different from moment frame connections studied thus far in this program. Funding is needed for this topic in the U.S.

2. Design Guidelines. Comprehensive design guidelines have been developed in Japan. This is a comprehensive book that synthesizes research results so that practicing engineers can design CFT structures. Funding is needed to support cooperative efforts between researchers and engineers for similar guidelines for U.S. It is expected that this document will be a somewhat shorter document that the Japanese guidelines, but the document would provide the full range of guidelines needed for U.S. practice.

3. **Frame Testing.** Considerable research on components has been completed, but funding is needed for frame and system testing to permit correlation of component test results with system behavior.

4. **CFT Column-Base Details**. Column base details will be different for CFT than for ordinary steel structures, and research is needed on this topic in the U.S.

5. **Post Earthquake NDE** (Non-Destructive Evaluation). After an earthquake occurs, it is difficult to evaluate the condition of the concrete inside the tube. U.S. engineers are concerned that rational methods be developed

6. **Fire Protection in CFT**. This issue appears to be essentially being resolved in Japan but considerable uncertainty remains in the U.S. Information exchange to U.S. from Japan is needed in this area.

COLLABORATION / COOPERATION

The following summarizes the personal collaboration and cooperation between Japanese and U.S. researchers as part of the CFT research effort.

- Tests of Beam- Columns between Lehigh and Kyushu University
- Tests of Rectangular CFT Connections between U. of Texas and Lehigh
- Tests of Circular CFT Connections between U. of Illinois and U. of Nebraska
- Bond Stress Transfer Information transfer between Japanese researchers, U. of Washington, Lehigh University, and U. of Texas
- 3D FEM analysis between U. of Texas, Chiba University and BCS (Building Contractor Society of Japan)

EXCHANGE OF DATA / RESULTS

The following summarizes the exchange of data and research results between Japan and the U.S. as part of the CFT research effort.

- Beam-Column data between U. of Minnesota and Mie University
- Bond Strength data between U. of Washington and Mie University
- Through Bolted Connection information between Lehigh and Mie University
- Connection data between U. of Texas and Lehigh University
- Design Guidelines have been completed in Japan and will be made available to all U.S. researchers
- Issues of Economy and Practicality of connections and details have been evaluated in Japan and should be evaluated by engineers and consultants in the U.S.

All CFT researchers are encouraged to provide summary information on their research projects for the Web page developed for this U.S.-Japan Program. All U.S. and Japanese researchers, who have not yet contributed to this effort, are encouraged to submit their summary in the near future.

EXCHANGE OF PERSONNEL

There have been several personnel exchanges between the U.S. and Japan in the CFT area during the past year. In particular, it is noted that A. Azizinamini and S. Schneider have made short term research visits to several Japanese institutions. Kazuhiro Uchida of Fujita Corporation visited the University of Texas. The CFT Group encourages the continuation of this exchange during the coming years.

PUBLICATION ISSUES

A number of papers have already been published in conferences and journals. However, the CFT Group strongly recommends that joint coordinated publications be prepared at the end of this U.S.-Japan Program. This will be difficult because of the difference in timing of the Japanese and U.S. efforts, and it is strongly recommended that special funding be available to facilitate this effort.

List of Participants
5th JTCC Joint Technical Sub-Committee Meeting on CFT Systems

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U.S.-Japan Cooperative Earthquake Research Program
Phase 5 - Composite and Hybrid Structures

THE FIFTH JOINT TECHNICAL
COORDINATING COMMITTEE MEETING
(Tokyo, Japan, October 5-7, 1998)

Report of the Working Group on Reinforced Concrete Column and Steel Beam Systems (RCS Technical Sub-Committee, TSC-2)

Sub-Committee Co-Chairs:
Prof. H. Noguchi, Chiba University
Prof. G. Deierlein, Stanford University

1. SUMMARY

The meeting of the RCS committee for the 5th JTCC included fourteen participants from Japan and seven from the United States. One full day of the meeting time was devoted to hearing sixteen presentations summarizing experimental and analytical research and the development of design criteria. As summarized below, from the U.S. side of the RCS committee there are six active projects and one completed project. On the Japanese side, all projects are either complete or very near to completion. However, significant efforts are still underway in both the countries to develop design criteria for composite RCS frames and to exchange research findings.

2. LIST OF PARTICIPANTS

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3. AGENDA AND SUMMARY OF PRESENTATIONS AT MEETING

3.1 Database of RCS test data and design standards

S. Iizuka/BCS - Reviewed development and evaluation of ultimate shear strength equation for RCS beam-column connection design models using data compiled in an electronic database that includes results from 450 RCS connection tests with over 190 catalog items per test. Of the 450 available connection tests, only 67 tests of through-beam type joints and 52 through-column type joints provide data that can be used to make valid comparisons with the proposed connection design models. The remainder of the tests cannot be used to evaluate the model because either (a) the tests are of a proprietary or specialized connection detail that is not represented by the design models, or (b) the connection subassemblies failed outside the connection and thereby do not provide behavioral information on the design model.

Y. Miyano/BCS - Reviewed development and evaluation a model to predict the beam-column joint shear deformation. As in the presentation by Iizuka, the proposed equations were compared to test data from the RCS connection database.

3.2 Tests of beam-column connections

Astaneh & Liu/UC Berkeley - A series of eight subassembly tests of shear tab connections between composite beams and steel connections have been completed, and a follow-up series is now in the planning phase. The shear tab connections are typically designed as “pinned” shear connections and are normally not considered as contributing any resistance to the lateral force resisting system in steel and composite frames. However, as these tests show, the horizontal force couple developed between the concrete floor slab and shear tab can resist significant moments with peak values on the order of 30 to 50% of the plastic moment capacity of the beam. This research project is being funded through the SAC Joint Venture and is not officially part of the NSF U.S.-Japan Program, but it relates to some of the projects in the U.S.-Japan project.

White & Leon/Georgia Tech - Progress is being made on a series of tests and analyses to examine the behavior of frames with steel columns, composite beams, and partially-restrained composite connections. Tests of four partially-restrained composite connection subassemblies (two exterior type and two interior type) are being planned with testing expected to commence in summer 1999. Additional cyclic tests of shear studs are also planned for summer 1999. Supporting analysis models are being developed to perform overall frame studies. The analysis software under development includes models for (a) composite beams with full and partial composite action, (b) multi-component behavior of partially restrained connections, (c) beam-column panel zones, (d) floor diaphragm constraints, (e) hysteretic behavior, and (d) torsional-flexural response of beam-columns.

Wight/Univ. of Michigan - Eight three-quarter scale exterior RCS beam-column joint subassemblies have been tested including one specimen made with steel fiber concrete and one with polymer fiber concrete. It is anticipated that two or three of the specimens will be repaired and re-tested. Overall, the tests confirm that the through-beam type RCS connections show generally good seismic behavior. Data from the latest series of tests provide information to help quantify requirements for maintaining bond transfer between the joint concrete and the vertical column reinforcement passing through the joint.

Bracci/Texas A & M - Six tests of RCS beam-column joints with concrete floor slabs have now been completed. Unique aspects of these tests are that (1) the connections are for interior locations in a space frame with beams running in the two orthogonal directions, and (2) the test assemblies include the beam slab. Over the course of the test program, several detailing innovations were made to improve performance of the connection for the beams in the discontinuous direction and to facilitate easier fabrication and construction. Overall, the tests demonstrate that the RCS connections showed good seismic behavior and are practical to construct.

Uang/U. of Calif. at San Diego - Three full-scale connections between steel beams and composite SRC columns were tested, two exterior connections and one interior connection. All utilized Reduced Beam Section (RBS or "dogbone") details in the steel beam to move the plastic hinge location away from the column. All specimens developed plastic hinge rotations in excess of 0.035 radians with no weld fractures.

Xiao/Univ. of Southern Calif. - Experimental studies are underway to investigate the behavior of steel and composite (SRC) columns subjected to constant axial load and cyclic shear in double curvature. Emphasis is on the evaluation of different shear resisting mechanisms and ductility. Tests of eight short columns currently in progress are intended to compare the behavior of columns with and without encased steel shapes and the effects of concrete strength and axial load.

3.3 Analysis of beam-column connections

Kanno/Nippon Steel - Presentation of bearing block tests conducted at Cornell University to provide data on the localized bearing strength of concrete as influenced by the bearing area, confining reinforcement, concrete strength, and other parameters. Data are compared with proposed design equations for bearing strength in composite RCS connections.

Noguchi and Uchida/Chiba Univ. - Overview of the development and application of three-dimensional finite element models of composite RCS beam-column connections. Eight-node low-order brick elements used to model concrete have been calibrated to experimental data to model the effects of concrete confinement, compressive strain softening behavior, and opening/slip behavior between steel and concrete. Color stress/strain contours from the FEM analyses were shown to be very useful in visualizing force transfer mechanisms in the connections. Comparisons of quantitative load-deformation results showed that the analyses were able to model the ultimate connection strength reasonably well, however, the FEM model did not accurately predict the inelastic connection stiffness.

3.4 Test and analysis of RCS frames

Y. Nishimura/Osaka Inst. Tech. - Described a two-story two-span RCS frame that was tested under reverse quasi-static loading. The frame was designed such that the plastic strength of the beams were nearly equal to the ultimate shear strength of the joints, so as to provide information on the interaction between frame and connection response. The frame withstood story drift ratios in excess of 0.05 without significant strength or stiffness degradation, thus confirming the reliable seismic behavior of RCS framing systems.

K. Uchida & Noguchi/Chiba University - Overview of detailed FE analyses of the frame tests conducted by Nishimura. Concrete columns, steel beams, and beam-column joints were modeled with finely meshed brick and shell finite elements. Results of static pushover analyses conducted independently and prior to the frame tests showed excellent agreement with the envelope of cyclic load-deformation behavior obtained from the tests.

Deierlein/Stanford Univ. - Presentation on analysis of RCS frames and review of seismic design issues and performance-based assessment criteria. Reviewed progress on developing and verifying nonlinear analysis models for determining the response of two- and three-dimensional RCS frames including the effects of RCS joint behavior, composite beam action, RC column behavior, and geometric nonlinear effects. Theme structure designs of six- and twelve-story RCS and steel framing systems have been completed and these will are now being used for system performance assessments. Development of several seismic damage indices were described along with plans to conduct reliability-based seismic performance analyses over the next few months.

3.5 Design guidelines

Kuramoto/BRI - Presentation on the development of equivalent viscous damping ratios for use in capacity spectrum approach for seismic performance assessment. Damping ratios are determined by the cumulative damping provided by inelastic action of various structural components (members and connections).

Nishiyama/BRI - Reviewed draft of proposed "Seismic Design Guidelines for Composite RCS Structural Systems" being developed in Japan. Guidelines include subsections outlining requirements for both current design methodologies (allowable stress/ultimate strength checks) and new performance-based criteria.

Deierlein/Stanford Univ. - Reviewed status of U.S. building code requirements for composite structures as represented in the draft to the 2000 International Building Code, the new section on seismic design requirements in the 1997 edition of the AISC Seismic Provisions, and the AISC-LRFD and ACI-318 codes. It is anticipated that participants of the U.S. side of the RCS subcommittee will participate in the updating to the 1994 ASCE Design Guidelines for Beam-column Connections Between Steel Beams and Composite Columns.

4. SUMMARY OF PROGRESS AND NEAR TERM PLANS

4.1 RCS beam-column connection testing: Including work in-progress, seventy-one RCS beam-column joint specimens will be completed as part of the U.S.-Japan program. These add to a database of over 400 tests of RCS joint subassemblies previously tested in Japan and 35 subassemblies previously tested in the U.S. In spite of the large number of previous tests, those conducted as part of the U.S.-Japan program are valuable in that they focus on parameters that have not been studied in prior tests, e.g., 3D joint details and loading, interaction of the floor slab and the beam-column joint, external joint details, and use of fiber reinforced concrete.

It is recommended that there be continued emphasis on sharing/exchange and critical review of test reports/papers between the Japanese and U.S. researchers. An important mechanism for such sharing is the electronic database of connection test data that has been compiled by the BCS in Japan. An English version of this database is available by from G. Deierlein at

Stanford University. During the next year, U.S. and Japanese researchers should incorporate new test data into this common database.

4.2 Composite PR beam-column connection testing: Researchers at Georgia Tech are planning tests of four subassemblies consisting of steel columns and composite beams connected by so-called composite PR (Partially Restrained) connections. This research builds on previous work in the U.S. and Europe dealing with a type of steel construction that utilizes slab action in transferring moments between the composite beam and steel column. A related study is the SAC Joint Venture Project at U.C. Berkeley on the moment restraint characteristics of composite shear-tab connections.

4.3 Member testing: Xiao and Anderson are currently conducting tests of encased composite SRC columns made with high strength concrete and to investigate shear-critical behavior.

4.4 Frame testing: RCS frame tests have been conducted in Japan by the Tokyu Corporation (1 test), the Nishimatsu Corporation (2 tests), the Okumura Corporation (1 test) and the Osaka Institute of Technology (1 test). Currently, there are no projects in the U.S. dealing with frame testing.

4.5 Analysis model development / verification: Efforts to develop, implement, and test new analysis formations for the inelastic analysis and design of RCS systems and components include the following:

University of Colorado - Model for composite beams including slip and partial composite action. This project is now complete.

Cornell & Stanford University - Interactive computer program call DYNAMIX (DYNamic Analysis of MIXed systesm) has been developed for the static and dynamic analysis of 2D and 3D steel and RCS frames including spread-of-plasticity effects for steel, RC, and composite members, cyclic stiffness degradation, and inelastic beam-column joints. Software is currently being used in cooperative research with the University of Central Florida and the Steel Structures Development Center of the Nippon Steel Corporation.

Chiba University and Fujita Corporation - Development and application of detailed FEM models for RCS frames and connection subassemblies.

Georgia Tech. - Development of analysis program for composite Partially Restrained frames consisting of composite beams and steel columns.

4.6 Theme structures: Japanese researchers associated with JSCA have developed and analyzed trial designs for six and twelve story RCS theme structures using AIJ design guidelines and criteria. Researchers at Stanford University have developed designs for six twelve story RCS theme structures based on the 2000 International Building Code requirements for the seismic design of composite structures. Inelastic static and dynamic analyses are currently underway to assess the seismic performance of these designs. Researchers at Georgia Tech will undertake related work for composite PR frames. Other groups in the U.S. whose main emphasis is connection testing (Univ. of Michigan, Texas A&M, and Univ. of California at San Diego) will also be developing some theme structure designs, but with the main emphasis of supporting their research on connection behavior.

4.7 Design models and criteria: One source of design criteria for composite RCS frames in Japan is a set of recommendations prepared by the Architectural Institute of Japan in 1994.

This document deals primarily with the design and detailing of RCS beam-column joints, and it has recently been translated into English by Kuramoto while he was in residence at Cornell University. The Japanese BRI is currently leading an effort to develop a more extensive document on RCS frame design, and a first draft of this is now complete and was presented by Dr. Nishiyama at the meeting. However, currently there are no plans to translate this document into English.

In the U.S., design criteria for RCS frames are available from several sources. The 1997 edition of the NEHRP Recommended Provisions and the latest working draft of the International Building Code 2000 include general design and seismic loading criteria for composite RCS frames. The 1997 AISC Seismic Provisions (Part II) include more detailed design criteria for composite RCS systems, members and connections. Additionally, a report published by the composite structures committee of ASCE in 1994 (Jl. of Struct. Engrg. In Aug. 1994) includes detailed design models and guidelines for RCS beam-column connections. Plans are underway for several U.S. researchers involved in the U.S.-Japan Program to participate in forthcoming initiatives within BSSC, ASCE, AISC, and ACI to develop improved and more comprehensive design criteria for RCS frames.

5. RECOMMENDATION FOR FUTURE WORK

5.1 Short term activities

The following is a summary of short term group activities that Japanese and U.S. participants should strive to accomplish in the next year that will require minimal resources:

Update RCS Connection Database: Deierlein from the U.S. and Furukawa and Kuramoto from Japan have offered to coordinate efforts to update the RCS connection database with tests that have been recently completed in the U.S. and Japan. Further, it has been proposed to investigate the possibility of publishing/archiving the database on a CD.

Development of Codes and Specifications: Several researchers (Deierlein, Wight, and Bracci) from the U.S. involved in RCS connection and frame studies have agreed to initiate an update to the 1994 ASCE Design Guidelines for Connections Between Steel Beams and Composite Columns.

Design Examples with Step by Step Procedures: To help facilitate transfer of knowledge of design procedures between U.S. and Japanese researchers and between researchers and engineers, it is recommended to develop and publish a number of step by step design examples of trial designs that include everything from overall system design to local connection design.

5.2 Longer term research initiatives

The following is a summary of areas where further research is needed to facilitate the design and use of composite RCS frames in regions of moderate- to high-seismicity (note that the initiatives are rated in terms of priority with H=highest priority and M=medium priority):

(H) RCS Frame Test - While several RCS frame tests have been conducted in Japan, these frames are not necessarily representative of practice in the U.S. The RCS subcommittee felt that it would be very useful to conduct a large-scale RCS frame test in the U.S. for or the following reasons: (1) the frame test would serve as a capstone project for the RCS research program and help tie together results of various projects, (2) the test would provide an opportunity to explore the relative advantages of various construction techniques, e.g., precast versus cast-in-place, for low-rise RCS frames, and (3) the tests would help confirm our understanding of overall system responses. It is further proposed that such a test should be planned by a team of researchers and industry participants. And finally, keeping in mind financial constraints, it is proposed that such a test would include the following features: (1) planar frame with slab, (2) at least three-quarter scale, two bays wide, and three-stories tall, and (3) tested pseudo-dynamically.

(H) Refinement & Calibration of Connection Design Equations - As noted above, many tests are now available to permit further refinement and calibration of equations and design models for composite RCS joints. A focused effort is needed to review and utilize this data.

(H) Bi-directional RCS Connection Tests - Tests conducted at the BRI in Japan indicate that there are some issues related to three-dimensional behavior that may warrant further study through 3D (bi-directional) beam-column connection tests.

(M) Testing of Full Scale RCS Beam-Column Joint - Nearly all of the RCS beam-column tests conducted to date have been on one-half scale or smaller specimens. It would be useful to run some tests of full-scale specimens, e.g., with W27 to W36 beams and correspondingly sized columns.

(M) RCS Braced Frames - All of the research conducted to date has focused on RCS moment resisting frames. Since braced RCS systems are also a viable option, research is needed to understand (1) the behavior of connections between steel braces and concrete columns, and (2) the overall system performance of braced RCS systems.

(M) Development Performance Based Design - Experimental and analytical research is needed to support the development of performance-based design criteria for RCS structures. Recent initiatives in Japan and the U.S. suggest that a key component of performance-based approaches will include quantitative criteria on permissible inelastic deformations (global and local) for various hazard levels.

(M) Repair/ Retrofit - Opportunities exist for the seismic rehabilitation and repair of structures using RCS framing concepts by jacketing (or otherwise reinforcing) seismically deficient steel framed structures.

(M) 3D FEM Connection Analyses - Research conducted at Chiba University indicates that detailed continuum finite element analyses can accurately model the inelastic behavior of beam-column joints and are an effective tool for understanding their behavior. Therefore, further research of this sort should be conducted to extend the range of parameters beyond what has been investigated experimentally.

(M) Fiber Concrete in Slab - Tests of RCS and composite PR connections with slabs have shown that the first mode of failure is localized crushing of the slab concrete around the column that leads to a large drop in strength and stiffness. Therefore, one possibility for improving the behavior is to use some type of fiber-reinforced concrete in the slab region around the column.

(M) Joint Bearing Failure Modes - Of the two predominate failure modes in composite joints, far more data is available on panel shear failure. Therefore, future connection tests and analyses should aim to focus more on bearing type failure modes.

(M) External Connections for Composite PR Frames - Current practice is to ignore composite action in flush external composite PR connections, i.e., connections where there is no slab overhand beyond the column. Therefore, there is an opportunity to improve the efficiency of these systems if details can be developed to mobilize slab action in the connection regions of external PR connections.

6. RESEARCH DISSEMINATION AND COLLABORATION

The following are suggestions for mechanisms to disseminate research findings of the U.S.-Japan Composite and Hybrid Structures Program to engineers, researchers, and educators in the United States and international community:

6.1 Conferences: Sessions that focus on the U.S.-Japan program are currently scheduled for the following upcoming conferences:

ASCE Congress '99 (New Orleans)
ASCCS-Los Angeles, Spring 2000.
Engineering Foundation - Composite Construction IV (Banff, Canada), May 28, 2000.
WCEE 12 - New Zealand, February 2000 (Note: Prof. Deierlein and Noguchi have submitted an abstract for an overview paper on the RCS program. Individual project leaders are encouraged to submit abstracts for papers with detailed results of their own research).

6.2 Journal publication: The RCS committee agreed at the meeting to assemble and publish papers on the RCS research from the U.S. and Japan in a special issue of an appropriate peer-reviewed technical journal.

The following is a preliminary list of the papers and paper authors from Japan:

1. Connection Tests:
   a. BRI (Kuramoto)
   b. BRI (Nishiyama)
   c. BCS (Furukawa)
   d. Chiba (Noguchi)
   e. Osaka (Nishimura)

2. FEM Analyses (Noguchi and Uchida)

3. Design Methods (Kuramoto et al.)
   - outline of frame design methods/requirements
   - detailed explanation of connection design models/equations

Paper topics and authors from the U.S. will be identified in early 1999.

The following are tentative target dates for developing the special journal issue:

December 1998 - Identify a journal for the special publication and develop the formatting requirements for the papers. Issue formal invitations to the Japanese authors. Invitations for the U.S. authors will be issued in early 1999.
September 1999 - Submission due data for papers from Japan (for peer review)
December 1999 - Submission due date for papers from U.S. (for peer review)

Journals where these papers might be published include: Engineering Structures, Journal of Const. Steel Research, EERI Spectra, ASCE Sruct. Journal, ACI SP, Earthquake Engineering and Structural Dynamics.

6.3 Web pages: U.S. researchers are encouraged to publish web pages to summarize recent progress on their work and to facilitate sharing of information. In Japan, researchers can post web-page updates through coordination with Prof. Noguchi who is maintaining a web site at Chiba University. It is emphasized that these web sites must be kept current (i.e., frequently updated) to be of interest and use to other researchers.

U.S.-Japan Cooperative Earthquake Research Program
Phase 5 - Composite and Hybrid Structures

THE FIFTH JOINT TECHNICAL
COORDINATING COMMITTEE MEETING
(Tokyo, Japan, October 5-7, 1998)

Report of the Working Group on Hybrid Wall Systems (HWS Technical Sub-Committee, TSC-3)

Sub-Committee Co-Chairs:
Prof. A. Wada, Tokyo Insitute of technology
Prof. J. Wallace, University of California, Berkeley

List of Participants

Japan-Side	**U.S.-Side**
Hiroyuki Aoyama	Abolhassan Astaneh-Asl
Toshimi Kabeyasawa	Sherif El-Tawil
Jun Kobayashi	Jerrome Hajjar
Yoshiyuki Matsushima	Sashi Kunnath
Tokie Nakano	Yahya Kurama
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Hidenori Tsukatami	Bahram Shahrooz
Akira Wada, Co-Chair	John Wallace, Co-Chair
Ken-ichirou Yamamoto	
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See Attachment A for addresses of participants.

Review of Recommendations from previous JTCC Meetings

The specific recommendations and findings of the previous JTCC Meetings were reviewed and discussed. Many of these recommendations were reaffirmed, since the work on the U.S. side is just starting to produce results and no new projects were added in Year 3. However, several new projects were added in Year 4 for HWS based on recommendations from previous meetings. The results of these discussions are summarized as follows:

Interaction of Systems:

Several investigations are being conducted to assess the interaction of components in hybrid systems. Limited work is underway to better understand the behavior of different hybrid wall systems and to establish design guidelines for these systems. Much of this work can be done through analytical studies; however, to ensure accuracy and reliability of such analyses, additional effort is needed to compare experimental data with results obtained using different modeling idealizations and numerical approaches. Several of the projects added in Year 4 focus on improving analytical models for the various structural components (beams, walls, connections, foundation), followed by system studies to study many of the items noted above. There was a sense that improving the models (developing and validating) would take substantial effort and that the effort needed to complete a comprehensive study of the above noted items may not be realistic within the duration of the U.S.-Japan program. There was an agreement that modeling and validation efforts should receive the highest priority, since conducting detailed studies with inferior models is not productive. There appears to be a need to better coordinate these studies within the U.S. The possibility of having several meetings in the U.S. over the next 12 to 18 months was discussed as a means to improve coordination.

Many of the complexities exhibited by coupled wall systems come from the nonlinear behavior of the coupling beams and the floor slab. Preliminary findings from the BRI study indicate that the effects of the floor slab on the behavior of the coupling beams may not be as significant as anticipated; however, additional studies are needed to confirm this finding for more general conditions. Additional experimental work also may be needed to address this issue.

The discussions reaffirmed that current studies should strive to:

- identify the optimal degree of coupling in between coupled shear walls,
- establish design oriented methods for estimating the variation of M, N and V in walls.
- establish the expected number and magnitude of cycles in coupling girders.
- evaluate the interaction of wall and perimeter frames, including the use of concepts such as top hat and intermediate level trusses.

Prediction of Wall Behavior under:

Variable M, N and V: In previous meetings, it was noted that there was a need to consider cases with higher axial loads representative of those that may be encountered in practice in the U.S. for tall core-wall buildings. One of the experimental studies in the U.S. will be conducted for higher axial load levels then previously noted to help address this issue. Variation of axial load during the test, to capture the effect of coupling beam shear on wall axial load, may also be included. Analytical models for walls are improving, but remain quite primitive relative to the actual cyclic behavior observed. Improved analytical idealizations, numerical procedures, and constitutive models are needed. Several projects were added in Year 4 hope to implement/improve micro- and macro-models for walls. Macro-models are attractive; however, for 3D analysis of complex wall and frame geometry, micro-models may be more effective.

Bi-directional input: Limited work has been done on this in Japan, focusing on L-shaped walls. Some work on T-shaped walls has been done in the U.S. These studies have focused on the estimating effective flange widths, detailing requirements, and strength issues. Behavior under biaxial loading has not been adequately studied; however, use of strain-based evaluation and current analytical tools may be sufficient to assess behavior for biaxial response. Limited experimental studies may be helpful in this regard.

SRC walls: Work on two types of walls with steel boundary elements are now underway in the U.S. Several issues discussed at previous meetings were at least partially addressed by the projects added in Year 4. The scope of these studies was expanded in Year 4 to consider a wide range of parameters. Variation of axial load and higher levels of axial stress may also be considered in one of the experimental studies based on previous discussions. All experimental studies are being conducted at reasonable scale, using realistic materials. This approach was reaffirmed at the 5th JTCC meeting. Two new experimental projects were added in Year 4 to investigate use of “innovative” systems.

Behavior of Coupling Girders:

Connections to Walls: Work on this topic has been done in the U.S. and Japan, as well as in other countries (e.g., Canada). Work is currently underway in the U.S. related to the connection of floor beams to the wall using simple connections to cover most likely connection cases for beams and top hat or floor trusses. The studies on moment connections have been dropped since the are not very effective relative to using trusses to establish coupling between the core and a perimeter frame. Issues related to the effect of slabs and local detailing of the wall at connection locations are also being investigated.

Reinforced Concrete beams: Questions were raised in discussions at the 3rd JTCC as to the detailing used for inclined bars and whether improved behavior (delay of spalling or bar buckling) could be achieved by different local details. This topic was not discussed at the 5th JTCC.

Slab effects: The effect of the floor slab on coupling beams was discussed at length at the 4th JTCC meeting. Given the number of presentations at the 5th JTCC meeting, this topic was not discussed further at the 5th JTCC; however, the HWS group reaffirms that this is an important issue and findings from previous meetings are still appropriate. There was limited discussion on the design of slab-wall connections. There appears to be a fundamental difference in the design approach used for this type of connection in the U.S. versus Japan. This general area is being addressed in one U.S. project added in Year 4; therefore, this topic will be considered for discussion at the next meeting after some detailed information is collected on the U.S. side.

Energy dissipation devices: At previous meetings, the idea of using energy dissipating devices was considered appealing; however, there was not a feeling that this was a high priority. As well, studies of this type appear to fall into the RFI area. Several "innovative" projects were added in Year 4 that fall into the HWS area. The work is being coordinated with the RFI group.

Foundation Effects:

Even though very little work has been done in this area, the importance of foundation effects was reaffirmed at the 5th JTCC meeting. Two U.S. projects added in Year 4 plan to include the influence of the foundation on the overall behavior and performance of the system. Participation of geotechnical engineers in these projects is encouraged. These studies will try to quantify the influence of foundation flexibility, which may lead to increases in plastic rotation demands on coupling girders and reduces in deformation demands on the walls. Foundation flexibility may also reduce the increase in girder axial load caused by foundation restraint of the transverse displacement between the walls. Current efforts are still somewhat limited and there may be room for more comprehensive studies in the future. Results of the studies would be widely applicable to HWS or RC wall systems.

Analysis Methods:

Because the early projects funded in the U.S. had a large experimental component, this topic has yet to be addressed in sufficient detail. Considerable effort has been expended on analytical studies of the theme structure and similar structures. These studies have helped identify modeling and analysis needs. More refined models are needed as are more efficient and stable solution strategies. Certain models have not been developed to the degree needed to examine local behavior; these include gap and slip models. Coordinated work, in cooperation with current studies and research conducted as part of other programs (e.g., the new Earthquake Centers), was discussed as a viable approach to addressing this need. In particular, the studies should address the following:

Dynamic analysis specifications: Number of modes, modal damping, stiffness (cracked vs. uncracked). In Japan, if dynamic analysis is done, it is usually nonlinear dynamic analysis.

Nonlinear Static Analysis (i.e., "pushover analysis"): Recent work in Japan has focused on application of nonlinear static analysis to HWS. Additional work is needed to develop/refine analysis and design methods. In particular, appropriate damping ratios to use in nonlinear static analysis should be studied for a variety of hybrid systems. Recent work in Japan on evaluating equivalent damping ratios is rather involved and it would be helpful if simplified/automated approaches were available.

Irregular buildings: While there are many needs to investigate irregular buildings, it was thought appropriate to focus efforts in this project on the specific problems raised by hybrid wall systems. Some of these problems might concern concentrated changes in strength or stiffness due to top hat construction, and the effects of in-plane diaphragm flexibility (rational estimation of collector and chord forces).

Core Wall Buildings: Typical building configurations with a core wall system and the surrounding frame could lead to torsional problems depending on the dimensions of the core and the surrounding frame. Analytical studies may be able to provide guidance on when torsion may be a problem where additional bracing of the frame may be needed; however, this is more likely to be productive after better analysis tools are available.

Trial Designs:

Parametric analytical studies: Studies have already been conducted in Japan. Comparison of response predictions would be useful considering different analysis models (single component vs. multi-spring; micro- versus macro-models). Issues related to performance based design criteria still need attention. Considerable work in Japan has been conducted on use of pushover analysis (e.g., FEMA 273) for HWS. Additional work is needed; however, it is important to have improved analytical tools before the results of such analyses would have broad impact. Limited studies are likely to be conducted with current projects in the U.S. Very detailed/comprehensive studies may need to wait until the very end of the program.

Design Methods:

Performance Based design: Some work has been done in Japan based on FEMA 273 and ATC-40. Some of this work includes very detailed evaluations to determine equivalent system damping ratios based on element demands. More effort is needed to determine the precise values associated with various response parameters and the relation between the response parameters for different performance categories. Work needs to be started on this topic in the U.S., although details may have to wait for the completion of the experimental studies. Integration of this work with the NSF Earthquake Centers would be appropriate.

Methods: Methods need to be devised for simplified design of walls and frame. This is being addressed in one of the U.S. projects, but on a limited scale. The need for additional study may need to wait for the results of current work.

R_W and D_S values: The HWS group reaffirmed that the use of performance based design approaches are preferred and tend to avoid the need to determine response modification factors as used with conventional design approaches.

Schedule:

Based on presentations at the meeting, the schedule for completing the hybrid sub-project was reaffirmed with minor modifications based on the Year 4 U.S. funding.

	1997	1998	1999	2000
Japanese-side	Design Methods	Monitoring U.S. activities	Monitoring U.S. activities	–
U.S.-Side	Testing	Testing and analysis	Testing, Analysis and Design	Analysis, Design, and Wrap-up

Summary of Current Work

A large number of presentations were made. Most of the projects in Japan have been completed. Three of the U.S. projects are ongoing and have been expanded in Year 4, and four new U.S. projects were added in Year 4. Much discussion took place related to each presentation. These presentations included:

J. Wallace

Tests on Walls with Steel Boundary Columns

Efforts since the 4th JTCC have focused on refining the experimental program. Parametric studies have been conducted to assess variation in wall designs due to the effects of coupling. Experiments to include specimens designed for low and moderate coupling. Main issues that have been studied include: wall boundary column size and orientation, wall shear stress at flexural capacity, anchorage of wall horizontal steel, confinement at wall boundary and web, and web vertical splitting. Additional funds were added in Year 4 to address several issues raised in the discussions at the 4th JTCC. The expanded scope includes testing additional walls so as to allow more parameters, such as: higher axial load levels, unsymmetrical cross-sections, and possibly the variation of axial load during testing. Specimens will be 16 ft (5 m) tall and 6 to 8 inches (150 to 200 mm) thick. ACI 318-99 provisions are being used to assess confinement requirements. All walls are being designed to require some level of confinement at the base of the wall. Construction and instrumentation of three wall specimens has started. Testing tentatively scheduled for late Spring through the summer. Testing to be announced via email.

Modeling studies will also be incorporated as part of the expanded study and coordinated with similar work for RC columns being done as part of the PEER Center. Both macro and micro wall models will be considered and calibrated with RC and SRC wall tests. Foundation modeling will also be studied. Co-PI's Joel Conte and Jonathan Stewart at UCLA were added to assist in the expanded project scope.

Needs: System response studies and development of performance-based design approaches using the models that are developed/implemented.

B. Shahrooz

Tests and analyses of coupled walls with composite girders

Modeling and design of composite coupling beams and RC walls was presented. Sensitivity studies of prototype structures were conducted to study the impact of flexible versus rigid floor diaphragm on overall response. Findings indicate that as the number of stories increase, the impact of a flexible diaphragm decreases. As well, the wall dominates the overall response of the building such that the diaphragm deformations are less important. A design model for plates embedded studs. Additional tests are being done to study the importance of wall cracking on connection requirements. Analytical studies have been used to determine test matrix. Floor slabs will be included on some of the specimens. Analytical models will be developed based on the experimental results.

A. Schultz/J. Hajjar

<u>Steel Moment Frames with Composite Infilled Frames</u>

This research is focused on shorter buildings (3 to 15 stories) in which steel moment-resisting frames with cast-in-place RC infill walls are used. The experimental program includes testing of eight shear connectors and two, two-story, one-bay frames. Designs for 3, 6- and 10-story prototype buildings were presented to address how the system can be efficiently used, as well as to study how frame-infill interaction impacts analysis and design. For low-rise buildings (3 to 6 stories), a core wall system such as that for the theme structure is viable. For taller buildings, perimeter walls are needed. With large overturning, the studs in the infill panels may be subjected to large tension.

Results from shear connector tests were also presented. Various parameters and reinforcing schemes were evaluated. The measured monotonic load-slip relation for studs is close to the PCI strength prediction and the overall relation matched reasonably well with that presented by Ollgaard. Results indicate that transverse tension has the greatest impact on stud behavior. Specimens subjected to cyclic loading (versus monotonic loading) achieved the same strength as those tested under monotonic loads; however, deformation capacity was significantly lower. Tests are complete and a report is being prepared.

Continuing work to focus on completing tests of two-story specimens and developing finite element models. FE models likely to be micro-models in 3D.

Needs: Behavior of studs for cyclic loads.

T. Kabeyasawa

Confinement Requirements for RC Walls

Confinement requirements at the corners of core walls against ultimate deformation demand were presented using a displacement-based approach to assess strain demands. The length of the "plastic hinge" is estimated based on experimental results. The procedure is evaluated using experimental results from the NEW RC Project.

Matsushima, Y.

Seismic Design Guidelines for Hybrid Wall Systems

A proposed draft for performance-based design of hybrid wall systems was presented at the 4th JTCC meeting. Based on the results from testing of a 12-story coupled wall structure at BRI, different damage levels for various limit states have been established. The damage levels, which are different for coupled walls, coupling beams, perimeter steel frames, cantilever walls, and the foundation, are quantified based on steel strain, level of cracking, deflection angle, and interstory drift angle.

Verification of seismic performance using static pushover analysis and equivalent sdof systems was the focus of the presentation at the 5th JTCC meeting. The overall evaluation procedure is similar to ATC-40 with studies to assess/verify performance. Effective height of 9th floor level for sdof analysis based on evaluation of all drift levels. Substitute damping level for the entire structure (12-story coupled wall) is based on summation of the damping ratio derived from force-deformation loops of individual components (strain level). Damping from 5 to 25% for displacement ductilities between one and ten for the coupling beams. Wall damping ratios of 0 to 25% for displacement ductility from 0 to 5 using results for first story. Overall structural damping ratio is 2 to 15% depending on performance level. From the evaluation, conclude that use of capacity spectrum with SDOF system is appropriate for HWS. This is primarily of function of well defined lateral deformations under earthquake demands. Use of sdof is very reliable for HWS, higher modes may contribute above 15 to 20 stories, but not that significantly. Higher mode response after wall yielding may be significant if few walls in the building.

Needs: The study has been limited to the 12-story coupled wall structure tested at BRI. Additional work is needed to broaden the scope of the work.

H. Astaneh-Asl

Studies of an Innovative and Traditional Composite Shear Walls

This is a new project added in Year 4 that will include analytical and experimental studies on composite shear walls. The walls will be either "traditional", with steel frame and concrete infill with a steel plate on one side, or "innovative", with rubber shims around the concrete to allow movement so crushing at the corners will not cause earlier deterioration in load-displacement response. A literature review has been completed and analytical studies and specimen design are underway.

A. Naaman

Innovative Hybrid Shear Walls with Steel Columns and HPFRCC Coupling Beam/Damper Elements

This is a new project starting in Year 4. The objective of the study is to assess the use of HPFRCC coupling/damper elements between steel columns. The elements could be used in either a vertical or horizontal orientation. It was noted that, depending on how the elements were used, out-of-phase behavior might be a concern. The impact of overturning on system performance, anchorage of the new elements to the steel frame, the potential to simplify the test set-up, and the need for analytical studies of system response to assess benefits of the system were discussed.
Needs: Interaction with, and input from, other researchers in the U.S.

S. El-Tawil/S. Kunnath

Seismic Behavior and Design of HWS

This is a new project starting in Year 4. The main objective of the study is to develop analytical models for HWS and to study of system response to assess efficient use of HWS. The DYNAMIX program will be used and both steel frame models and wall macro or micro models will be incorporated. More likely that micro models will be used since it is possible (easier) to incorporate connection details and 3D behavior. Also plan to conduct sensitivity studies on the impact of the foundation on HWS response. Overall plan is to build on existing work in RCS and HWS programs, as well as prior work on rc walls.
Needs: Experimental data for RC and SRC walls.

Y. Kurama

Seismic Design and Parametric Response Evaluation of Unbonded Post-Tensioned Hybrid Coupled Walls

This is a new project starting in Year 4. The main objective of the study is to evaluate overall HWS response and to develop an unbonded pt coupled wall system where the coupling beams are not embedded into the wall. First phase of the study will involve analytical studies to determine feasibility of the system. Gap opening is required for the system to work; therefore, use of light seat angles to connect the beam to the wall is being studied. PT strands run inside the wall. Beam will be designed to remain linear elastic, all deformation will be accommodated at the ends of the coupling beams through gap opening. Energy dissipation in the clip angles for service level earthquake, inelastic behavior in angles for repair level earthquake. PT will not yield until repair or ultimate level earthquake. Development of an analytical model has been started using fairly detailed nonlinear elements.

Kobayashi, J.

Steel Beam Connections in HWS

r moment connection of steel beams to the rc core in HWS, special detailing is needed for deformation compatibility between frame and wall; however, efficient coupling is hard to achieve with moment connections (trusses are often used). It would be logical to avoid this problem by designing the connection as a pinned connection. But in reality, true pin joints are very difficult or expensive to obtain; therefore, semi-rigid connections are most likely. The objective of this study is to assess most economical connections and determine stiffness and strength for analysis and design. The "in-wall" connection should be designed to be strong and the "beam-end" connection should be designed to be ductile. A procedure was presented to determine what level of moment capacity and detailing should be provided at beam-to-wall connections. Design charts aid in this process.

A lengthy discussion followed concerning the importance of the axial force transfer at beam-to-wall connections. Japanese practice is to connect the slab to the wall and to assume a rigid diaphragm. In the U.S., the slab might not be connected and axial force transfer would occur through the beam, which would influence the connection requirements.

Needs: How to economically achieve pin connections. Differences in U.S. and Japanese practice for slab-beam-wall connections need to better understood.

Kobayashi, J.

Coupling beams with diagonal reinforcement

havior of coupling beams with diagonal reinforcement and shear span ratio between approximately 0.5 to 2 was the topic of the presentation. Load-displacement relationship for these beams was evaluated for cracking, yielding, and ultimate limit states. Cracking strength taken as the smaller of the load for flexural cracking or shear cracking. For yield strength, a strut and tie model or a model based on flexural strength is used. The flexural strength mode uses equilibrium requirements and geometry of the beam, and accounts for both diagonal and parallel steel. Ultimate strength assessed using standard approaches. Yield deformation determined based on one of several approaches depending on the case. Ultimate at 90% of max load.

Comparisons with 70 tests reveals that that the trilinear envelop predicts the load-displacement relation reasonably. This data set may be valuable for other researchers in the HWS group.

Nakano, T

Design Example of 12-Story Office Building

Design example based on 12-story RC coupled wall test structure to verify seismic performance using performance levels L1-L4 and damage states D0-D3 defined in an earlier presentation. Approach similar to ATC-40 using pushover analysis to response point for several performance levels. Damping of 8, 16, 21% at operation, repair, and ultimate limit states. Overall process (especially assessing damping) is a lot of effort for designer; however, the structural engineers in Japan are comfortable with the process.

_*Needs:* Similar work is needed in the U.S. Damage states may be different for RC versus SRC construction.

Tsukatani, H.

Performance Levels for RC Core Walls with Perimeter Frames

Studies of three buildings, 10, 18, and 28 stories tall were used to assess performance levels and damage states for buildings will core walls and perimeter frames. Hat truss used on 18 story building, and hat and belt truss for 28 story building. Four performance levels defined (L1 – L4) and four damage states (D0 – D3). Performance levels are then related to the damage states.

Major Findings and Accomplishments

Since the last meeting of the JTCC, the following major accomplishments were achieved related to behavior, analysis and design.

Regarding Behavior:

- Stud connection tests indicate that transverse tension, confinement details, and cyclic loading are the key factors affecting the strength and deformation capacity of stud connections for RC infill panels in steel frames.
- Behavior of embedded stud connections for beams-to-wall connections have been tested and a design model has been developed.

Regarding Analysis:

- Multi-spring models were able to simulate redistribution of forces exhibited by coupled wall systems, whereas simpler elastic, parallel, or truss element models were not.
- Dynamic analyses indicate adequate behavior of hybrid wall systems.
- Consideration of flexible floor diaphragms in buildings more then three stories is not necessary.
- ATC-40 and FEMA-273 type approaches appear to be well suited for coupled and isolated walls in HWS.
- Assessing equivalent damping ratios for use with ATC-40 type approaches is either quite subjective or relatively laborious (if assessed on an element-by-element basis).
- Trilinear relations based on cracking, yielding, and ultimate states can be derived to represent the behavior of diagonally reinforced coupling beams.
- Use of RC infill panels is not viable for taller core wall buildings due to the demands placed on the studs.

Regarding Design:

- Design of slab-wall connections may differ significantly in the U.S. and Japan. These differences need to be better understood and care must be exercised in applying the research results.
- Research continues to verify that Hybrid wall systems are good at controlling lateral displacements and providing good energy dissipation.
- Damage states from pushover analysis compares well with damage observed from tests of walls and coupled walls.
- A design procedure for embedded plates with multiple studs has been proposed and evaluated.

Future Research Needs and Priorities

With the addition of several new projects in Year 4, there are a considerable number of U.S.

projects underway. However, there remain a number of issues requiring additional research and development as noted below:

1. Improved element modeling options - more accurate and reliable models and methods are needed to help assess behavior of elements and systems. The effort should focus on developing tools for 3D analysis as well as simplified tools for two- and three-dimensional analysis. Research in this area should be well coordinated within the HWS program as well is with other research being conducted in the U.S. (e.g., with the NSF earthquake centers and other U.S.-Japan research programs).

2. Development of performance-based design guidelines. Performance levels and damage states need to be identified. A working group may be needed to develop this information.

3. Additional studies for a wider range of floor plans and building heights than those considered to date.

4. Additional studies of the effects of foundation flexibility on displacements, girder rotation demands, and inelastic force redistribution.

5. Parametric analytical studies considering bi-directional dynamic input and response, and near-fault ground motions.

6. Development and assessment of simplified design and analysis methods, including an assessment of static pushover and dynamic analysis procedures.

7. The interaction of steel and concrete elements at interfaces with welded, headed anchor studs or other anchors is needed for cyclic loads.

8. A large-scale test of a complete system of core wall and steel frame is needed to assess combined system behavior and to validate analytical and experimental results. The tests should be most likely be done under cyclic, slow-rate loading.

9. Additional input is needed from industry to address constructibility issues.

Recommendations and Plans

A number of specific recommendations and plans were formulated for the coming year.

Future Work:

Considerable experimental results will be produced on the U.S.-side in the coming year. The 6th JTCC meeting should provide an opportunity for U.S. researchers to present these results. Consideration should be given to conducting a large-scale test of a HWS under cyclic, quasi-static loads to pull together the information generated in the HWS program.

There is a significant need to improve the analytical tools available to researchers to model and evaluate the performance of hybrid wall systems. Current tools are quite archaic, with limited modeling options and graphics. Development of robust analysis tools should be addressed. This should be coordinated with ongoing research and new research centers and other research to maximize the benefits. These needs are being partially addressed within the new projects added in Year 4; however, additional work is needed. Coordination of this work is essential so that the program modules produced are well documented and widely available.

Performance levels and damage states need to be evaluated for HWS. This may be difficult within the current program; however, it would appear to fit into the new U.S.-Japan program. A working group should be assembled to address this issue. A group that includes participation from HWS, RCS, CFT, and RFI may be appropriate.

Greater emphasis will be placed on dissemination of the findings of the project. This may take the form of a “special publication” or a coordinated submittal of papers to a journal. Various options for this are being considered. A summary session for the overall U.S.-Japan project was proposed for the 12WCEE.

Loading Histories and ground motions:

Sets of ground motions were generated for several U.S. sites as part of the SAC Steel Project. These are available through the SAC WWW site. In addition, ground motions for Japan are available through the WWW sites for the Agency for Science and Technology and the Architectural Institute of Japan. An effort is needed on part of the JTCC to select a set of ground motions to allow consistent comparison of the theme buildings. Efforts are underway to revise the ATC-24 loading protocol in the U.S. This information will be distributed to the U.S. and Japanese participants for their consideration. The U.S. participants initiating testing programs are encouraged to coordinate the selection of loading histories and instrumentation protocols.

Exchange of data and results:

Investigators are encouraged to disseminate their experimental data on the Composite and Hybrid Structures project WWW site.

Exchange of Researchers:

No immediate plans were discussed at the meeting. Researchers were encouraged to take advantage of existing programs for collaboration.

Attachment A: Roster of Participants

Joint Technical Sub-Committee Meeting on Hybrid Wall Systems

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U.S.-Japan Cooperative Earthquake Research Program
Phase 5 - Composite and Hybrid Structures

THE FIFTH JOINT TECHNICAL
COORDINATING COMMITTEE MEETING
(Tokyo, Japan, October 5-7, 1998)

Report of the Working Group on Research for Innovation (RFI Technical Sub-Committee, TSC-4)

Sub-Committee Co-Chairs:
Prof. A. Tanaka, Utsunomiya University
Prof. S. Goel, University of Michigan

List of Participants

Japan - Side	U.S. - Side
H. Fukuyama	H. Astaneh
N. Iwabe	S. Goel
T. Nagao	N. Krstulovic-Opara
Y. Sato	V. Li
A. Tanaka	A. Naaman
H. Yamanouchi	J. Wight

Research Activity

The group felt that an integrated, i.e., “holistic” approach to the development of both advanced composites and innovative structural systems is important for successful and cost-effective system performance. The framework of this approach is shown in Figure 1, where the objective criteria include: cost-effectiveness, ductility, strength, and weight.

Specific topics investigated in the ongoing projects include (**a**) development of advanced composites, and (**b**) development of innovative structural systems made by the selective use of both conventional and advanced composites. Covered topics are very much in agreement with the priorities and recommendations made during previous JTCC meetings. Results indicate that both selective use of advanced composites and use of innovative structural concepts provides excellent seismic performance.

A) Development of Advanced Composites: Research activities in the RFI group in the area of advanced cementitious composites include development of:

1) **Fiber Reinforced Concretes** (FRCs) that exhibit **(a)** high ductility, such as steel fiber FRCs, **(b)** very high ductility, such as FRC made with polyvinyl alcohol (PVA) fibers called PVA-Engineered Cementitious Composite (PVA-ECC), and **(c)** high ductility, high strength and light weight, such as steel fiber High-Strength Lightweight-Aggregate FRCs (HS-LWA FRC), and
2) **High-Performance FRCs** (HPFRCs) exhibiting very high strength and very high ductility in both tension and compression, such as steel fiber Slurry Infiltrated Fiber Concrete (SIFCON) and Slurry Infiltrated fiber-Mat Concrete (SIMCON).

B) Development of Innovative Elements / Systems: Research activities in the RFI group in the area of innovative structural elements and systems include:

1) development of very lightweight and high strength elements made using ultra lightweight concrete,
2) use of FRP composites in: **(a)** development of novel high-performance reinforced concrete elements made with FRP mesh reinforced mortar panels, **(b)** seismic retrofit methods using FRP-sheet wrapping, and **(c)** innovative application of FRP in structures that need to meet special electric / electromagnetic requirements,
3) development of high - performance composite (i.e., steel and concrete) shear walls exhibiting two-phase hysteretic behavior,
4) development of novel frame systems using FRC encased steel joists,
5) development of high-performance composite structural systems through a selective use of HS-LWA FRC and HPFRCs including (a) SIFCON plastic hinge elements, (b) SIMCON stay-in-place formwork elements, and (c) SIMCON "fuse" jackets,
6) development of wall panels for seismic retrofit and plastic beam - hinge elements using PVA-ECC,
7) development of hybrid shear walls with HPFRC (i.e., SIFCON) coupling beam dampers, and
8) development of RCS joints with FRC and PVA-ECC.

A list of specific presentations on RFI conducted during the meeting is shown in Table 1.

Table 1: List of presented papers.

Presenter	Paper Authors	Paper Title	Topics Covered
H. Fukuyama and Y. Sato	A. Tanaka. Y. Matsuzaki, A. Mikame, H. Fukuyama and Y. Sato	**Japanese Research Activities on RFI**	ultra lightweight concrete, ductile FRC (PVA-ECC), FRP-mesh reinforced concrete, FRP sheets for seismic retrofit
A. Astaneh-Asl	Astaneh-Asl	**Seismic Studies of Innovative and Traditional Composite Shear Walls**	high - performance composite shear walls exhibiting two-phase hysteretic behavior
S. Goel	S. Goel	**Concrete-Encased Steel Composite Joists for Seismic Resistance**	FRC-encased steel joist frames
N. Krstulovic-Opara	N. Krstulovic-Opara, S. Ahmad, and P. Zia	**High-Performance Composite Infrastructural Systems Utilizing Advanced Cementitious Composites**	composite RCS/CFT frames made with SIMCON, SIFCON and HS-LWA FRC
V. C. Li	V. C. Li, H. Fukuyama and A. Mikame	**Development of Ductile Engineered Cementitious Composite Elements for Seismic Structural Applications**	wall panels for seismic retrofit and plastic beam - hinge elements using PVA-ECC
A. E. Naaman	A. E. Naaman	**Innovative Hybrid Shear Walls with Steel Columns and**	hybrid shear walls with HPFRC (i.e., SIFCON)

		HPFRCC Coupling Beam-Damper Elements	coupling beam dampers
J. K. Wight	J. K. Wight	**Behavior of RCS Connections Subjected to Seismic Loading**	RCS joints with FRC and PVA-ECC

Future Research Directions, Needs and Priorities

A variety of future research needs regarding the development of advanced materials and structural systems was identified and discussed. The group concluded that the following additional topics should be addressed in future research (list provided in prioritized order):

1) selective use of advanced composites (e.g., HPFRCs, FRCs, and FRPs) in critical regions of both conventional and novel structural systems.
2) development of innovative structural elements and systems,
3) investigation of (a) material behavior of advanced composites under reversed cyclic loading, and (b) development of procedures for predicting response of composite structural members and sub-assemblages under reversed cyclic loading, using information obtained in (a),
4) cost-effectiveness and constructability studies,
5) fire-resistance studies,
6) development of new advanced composites.

The group also decided that the following action items should be conducted jointly by both the Japanese and the U.S. side:

1) development of a State-of-the-Art report on the entire RFI program, to be completed by December 2,000. The group plans to prepare a joint proposal to NSF, BRI, BCS and JSCA for necessary funds.
2) development of joint proposal for full-frame testing of FRC encased steel joist systems, and
3) seek platform for continued collaborative research efforts in RFI.

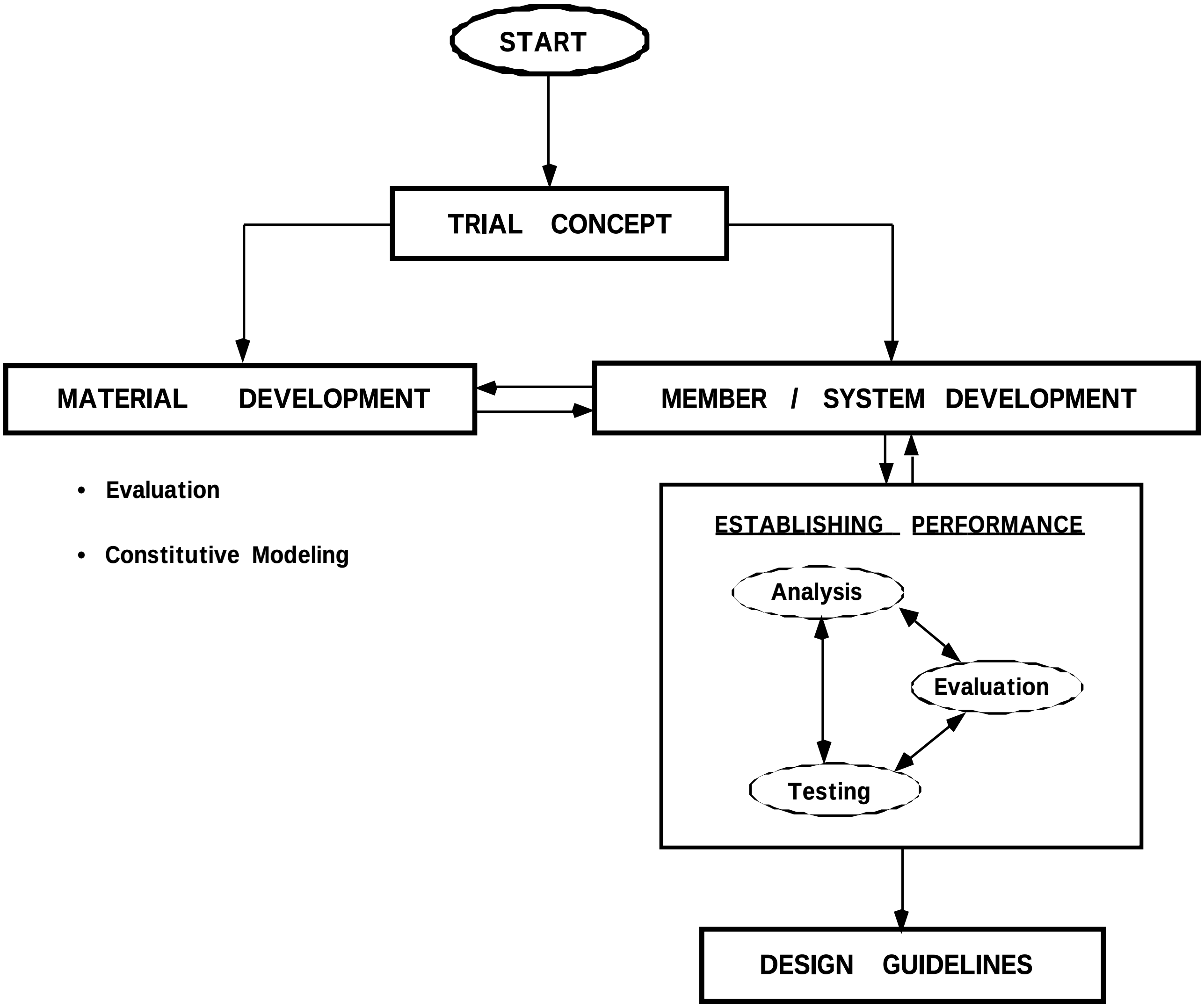

Figure 1: Flow-chart of the suggested "holistic" approach to material and (structural) system development.

LIST OF MATERIALS

The following materials are used for discussions in summary session and each technical subcommittee sessions.

CFT

1) CFT research progress in Japan
2) Guidelines for the design of CFT column system
3) Behavior of beam-to-column connection of CFT column system
4) Design example of CFT structure
5) Trial design of CFT theme structures (1) -Comparison between CFT system and S system in a common design-
6) Trial design of CFT theme structures (2) -Elasto-plastic characteristics of CFT-
7) Development of design criteria for steel beam to concrete filled tube column connections in seismic regions
8) Seismic behavior and design of moment connections for CFT column-systems
9) Seismic behavior of high performance CFT beam-columns

RCS

1) RCS research program in Japan
2) Seismic resistance of exterior SRC connections
3) Compilation based on the data base of the RCS joint
4) Experiment on composite RCS frame with through beam type joints
5) Bearing strength of joints between steel beams and reinforced concrete columns
6) Bearing strength of RCS joints
7) 3-D finite element analysis of stress transmitting mechanism in RC column - S beam joints
8) FEM analysis of 3-D RCS joints
9) Nonlinear three-dimensional finite element analysis of RCS frame
10) Equivalent damping factor of composite RCS frames
11) Seismic behavior of composite RCS frame systems
12) Experimental studies of seismic behavior of shear connections with floor slabs
13) Three-dimensional slab effects in partially-restrained composite construction
14) Experimental studies of C-SMR connections with reinforced-concrete-encased column and steel beams
15) Seismic behavior of steel and concrete composite short columns
16) Towards the performance-based design of composite RCS moment frame buildings
17) Seismic design guidelines for composite RCS structural systems (draft)

HWS

1) Seismic design guidelines for hybrid wall system (HWS) structures -Verification for seismic performance-
2) Scope of application
3) Design of connections between RC walls and steel beams in HWS structures
4) Strength and deformation capacity of RC coupling beams for HWS structures -Diagonally reinforced concrete beams-
5) Testing of shear walls with embedded steel sections
6) Innovative hybrid shear walls with steel columns and HPFRCC coupling beam-damper elements
7) Seismic design and parametric response evaluation of unbonded post-tensioned hybrid coupled walls
8) Seismic studies of an innovative and traditional composite shear walls

9) Composite interaction of steel frame members and reinforced concrete walls under seismic loading
10) Seismic behavior of composite coupled walls: Coupling beams including slab and system
11) RC/Composite wall-steel frame hybrid buildings: Connections and system behavior
12) Seismic behavior and design of hybrid wall systems
13) Seismic behavior of steel moment-resisting frames with composite reinforced concrete infill walls
14) Design example of 12-story office building
15) Confinement design of core wall against ultimate deformation demand

RFI

1) Japanese research activities of RFI
2) High-performance composite infrastructure systems utilizing advanced cementitious composites
3) Development of ductile engineered cementitious composite elements for seismic structural application