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

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

(Monterey, CA, October 12-14,1997)

Edited by

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

Fourth Joint Technical Coordinating Committee Meeting (4th JTCC)
October 12-14, 1997
Hyatt Regency Hotel, Monterey, California

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); and RC/SRC Wall Systems (HWS); 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 pheasibility 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, and the third in Hong Kong in December 1996. 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 4th JTCC Meeting - research summaries, resolutions and recommendations. It is anticipated that several more meetings will be held in the coming years prior to the successful completion of the program.

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

Fourth Joint Technical Coordinating Committee Meeting (4th JTCC)
October 12-14, 1997
Hyatt Regency Hotel, Monterey, CA

(Final Program)

Sunday, October 12

Introduction Chairmen: Aoyama/Mahin

1:00 Welcome (Mahin, Aoyama, S.C. Liu)
Meeting Schedule/Objectives (Goel, Yamanouchi)

Summary Session Chairmen: Aoyama/Mahin

1:30 - 2:20 CFT Research Program (Roeder/Morino)
2:20 - 3:10 RCS Research Program (Deierlein/Noguchi)

3:10 - 3:40 Coffee Break

3:40 - 4:20 HWS Research Program (Mahin/Wada)
4:20 - 5:00 RFI Research Program (Goel/Tanaka)
5:00 - 5:30 Ground Motions (Deierlein/M.Watabe)

6:30 Reception/Dinner (hosted by U.S. side)

Monday, October 13

8:30-12:00 Parallel Joint Technical Subcommittee (JTSC) Sessions

Presentation of Progress Papers by Researchers; Discussion

JTSC 1 - CFT Co-chairmen: Roeder/Morino
JTSC 2 - RCS Co-chairmen: Deierlein/Noguchi
JTSC 3 - HWS Co-chairmen: Mahin/Wada
JTSC 4 - RFI Co-chairmen: Goel/Tanaka

12:00 Lunch (separate in each group)

1:30-4:30 Parallel Joint Technical Subcommittee (JTSC) Sessions (Continued)

Presentation of Progress Papers by Researchers; Discussion

6:30 Dinner (hosted by Japan side)

9:00 JTSC Co-chairmen's Meeting as needed

Tuesday, October 14

8:30-11:30 Parallel Joint Technical Subcommittee (JTSC) Sessions (Continued)

Discussion and Preparation of Summary Reports

JTSC 1 - CFT Co-chairmen: Morino/Roeder
JTSC 2 - RCS Co-chairmen: Deierlein/Noguchi
JTSC 3 - HWS Co-chairmen: Wada/Mahin
JTSC 4 - RFI Co-chairmen: Goel/Tanaka

11:30 Lunch (separate in each group)

Closing Session Chairmen: Aoyama/Mahin

1:00 - 1:30 Concept of Modification of Japanese Bldg. Std. Law (Hiraishi)
1:30 - 3:00 Final JTSC Reports (Research Plan, Gaps)

3:00 - 3:30 Break

3:30 - 4:20 Recommendations, Resolutions
4:20 - 4:30 Closing Remarks
4:30 Adjourn

OHP and Slide Projectors are available on the 1st and 2nd days, and only OHP is available on the last day.

PARTICIPANTS LIST (JAPANESE SIDE)

BRI : Building Research Institute
BCS : Building Contractors Society
JSCA: Japan Structural Consultants Association

H. Aoyama (Aoyama Laboratory)(Chairman)(CFT,RCS,HES,RFI)
A. Tanaka (Utsunomiya U)(RFI)
S. Morino (Mie U)(CFT)
K. Sakino (Kyushu U)(CFT)
H. Noguchi (Chiba U)(RCS)
M. Watabe (Keio U) (RFI)
Y. Nishimura (Osaka Institute of Technology) (RCS)
A. Wada (HWS)
T. Kabeyasawa (U of Tokyo) (HWS)
S. Sugano (Takenaka Co./BCS) (CFT,RCS,HWS,RFI)
K. Yoshioka (Obayashi Co./BCS)(CFT)
N. Sakaguchi (Shimizu Co./BCS) (RCS)
J. Kobayashi(Taisei Co./BCS) (HWS)
A. Mikame (Fujita Co./BCS) (RFI)
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Y. Hayashi (Kajima Co./JSCA) (CFT)
O. Mori (Toyo Co./BCS) (CFT)
T. Noguchi (Aoki Co./BCS) (CFT)
K. Uchida (Fujita Co.) (CFT)
H. Kamura (Nihonkokan Co.) (CFT)
H. Karamoto (BRI)(RCS)
K. Sugihiro (Mitsubishi Co./BRI) (RCS)
H. Itadani (Omoto Co./BRI) (RCS)
Y. Masuda (Obayashi Co./BCS) (RCS)
K. Yoshimatsu (Kumagai Gumi Co./BCS) (RCS)
S. Iizuka (Nichimatsu Co./BCS) (RCS)
E. Ishii (Taisei Co./JSCA) (RCS)
M. Mizuta (Obayashi Co./JSCA) (RCS)
M. Teshigawara (BRI) (HWS)
Y. Matsushima (Fudo Co./BRI) (HWS)
S. Sasaki (Fujita Co./BCS) (HWS)
T. Kei (Takenaka Co./BCS) (HWS)
N. Nagao (Nihon Sekkei Inc./JSCA) (RFI)
N. Iwabe (Yamasita Inc./JSCA) (RFI)
K. Nishimuko (BCS) (CFT,RCS,HWS,RFI)
N. Omata (Building Center of Japan (BCJ)) (CFT,RCS,HWS,RFI)

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Atrorod Azizinamini (U of Nebraska)(CFT)
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Joseph Bracci (U of Texas A&M)(RCS)
Gregory Deierlein (Cornell U)(RCS)
Filip Filippou (UC Berkeley)(RCS)
Dan Frangonpol (U of Colorado)(Observer)
Subhash Goel (U of Michigan) (Coordinator)(RFI)
Jerry Hajjar (U of Minnesota)(HWS)
James Jirsa (UT Austin)(CFT)
Neven Krstulovic-Opara (NC State U)(RFI)
Reoberto Leon (Georgia Tech)(RCS)
S-C Liu (National Science Foundation)
K-C Tsai (Observer)
Stephen Mahin (UC Berkeley)(Chairman)(HWS)
Walter Moore (U of Texas A&M)(RCS)
Khalid Mosalam (Observer)
Vilas Mujumdar (Calif. Div. of State Architect)
Charles Roder (U of Washinfton)(CFT)
Stephen Schneider (UI, Urbana)(CFT)
Art Schultz (U of Minnesota)(HWS)
Benson P. Shing (U of Colorado)(RCS)
Enrico Spacone (U of Colorado)(RCS)
C-M Uang (UC San Diego)(RCS)
John Wallace (UCLA)(HWS)
Don White (Georgia Tech)(Observer)
James Wight (U of MIchigan)(RCS)
Loring Wyllie (Degenkolb Engineers)
Yan Xiao (USC)(RCS)
Prof. Choi (Observer)

US-Japan Cooperative Earthquake Research Program
Phase 5 - Composite and Hybrid Structures

SUMMARY, RESOLUTIONS AND RECOMMENDATIONS OF THE FOURTH JOINT TECHNICAL COORDINATING COMMITTEE MEETING (Monterey, CA., October 12 - 14, 1997)

SUMMARY

The Fourth Joint Technical Coordinating Committee (JTCC) Meeting of the US-Japan Cooperative Earthquake Research Program on Composite and Hybrid Structures was held at The Hyatt Regency Hotel in Monterey, CA., on October 12-14, 1997. A total of seventy one attendees participated in the meeting.

On the first day of the JTCC meeting (October 12), the general session was held in which summaries and progress of research work on both sides were presented and reviewed.

During the second full day (October 12) and half day on the third day (October 14), 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 second half of the third day (October 14) - the plenary session, 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 Monterey, CA. 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 at an increased level.

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. Scope of this program may be expanded to include more thorough examination of promising innovative technologies and materials (such as those explored in the RFI Program) applied to repair and upgrading of existing structures, application to infrastructure systems, and so on.

4. Efforts to synthesize and interpret knowledge gained in the program, and to disseminate this knowledge and design/analysis methodologies to the design profession and industry should be accelerated.

5. Consideration should be given to perform testing work on carefully selected full frames in possible cooperation with other research programs.

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

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

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

9. Use of common set of ground motions is encouraged to permit more direct comparison of dynamic analysis results.

10. The funding agencies in both countries should maintain proper balance of research effort among the four arbas of the program. consistent with is the research needs.

11. Funding should be revised for joint coordinated publication of research work with practical implications.

12. The 5th JTCC meeting should be held in early fall of 1998 at a place to be hosted by the Japan side.

Report of the Working Group on Concrete Filled Tube Column System (CFT Technical Sub-Committee, TSC-1) Meeting October 13-14, 1997

Participants

Japanese Participants:
- S. Morino (Co-Chair)
- K. Sakino
- I. Nishiyama
- A. Mukai
- K. Yoshioka
- E. Inai
- T. Noguchi
- O. Mori
- Y. Hayashi
- H. Kamura
- T. Fujimoto
- K. Uchida

US Participants:
- C. Roeder (Co-Chair)
- F. Filippou
- A. Azizinamini
- S. Schneider
- J. Jirsa
- Le-Wu Lu
- A. Ayoub
- J. Ricles

Germany:
- J. Bouwkamp

See attachment for email addresses and affiliations.

Presentations were made on research projects

Projects on Japanese Side

1. E. Inai, "Analytical Model for Flexural Behavior of CFT Beam Columns"
2. K. Sakino, "Experimental Studies and Design Recommendations on CFT Columns"
3. T. Noguchi, "Deformation Capacity of CFT Beam-Columns"
4. O. Mori, "Stiffness Degrading Ratio of Concrete Filled Steel Tubular Columns"
5. A. Mukai, " Modeling Procedure of CFT Beam-Columns"
6. T. Fujimoto, "Test Results of CFT Beam-to-Column Connection"

   K. Yoshioka, "Supplemental Test Result Information"

Projects on US Side

1. Stephen Schneider, "Summary of Connections to Concrete-Filled Tube Columns"
2. Atorod Azizinamini "Development of Design Criteria for Steel Beam to Concrete Filled Tube Column Connections in Seismic Regions"

   Filip Filippou, "Discussion of Supporting Analytical Studies"

3. Charles Roeder, "Stress Transfer Between Steel and Concrete in Composite and Hybrid Construction"

4. James Ricles, " Seismic Behavior of Moment Connections for CFT Column-Systems"

5. James Jirsa, "Progress Report on: Moment Connections Between Steel Beams and Concrete-Filled Steel Tubular Columns"

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

US Projects which was noted but not presented

1. G. Lee, "Aseismic Behavior of Concrete-Filled Tubular Columns"

Summary of Progress - Items in progress are noted as such

The Japanese testing program is clearly near completion while the US program is clearly in the middle stages. Japanese work is now evolving 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 nearly been completed in Japan, and an extensive test program is approximately half completed in the US. 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. **CFT Member Behavior**. An extensive test program on member behavior including concentrically loaded columns, eccentrically loaded columns and beam columns has been completed in Japan. Data analysis is also quite advanced, and significant progress has been made toward developing nonlinear models for this behavior. In the US, a few tests have been completed and a more extensive test program is just started.

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 US. A study on bond stress transfer between steel and concrete is nearly completed in the US and smaller related studies are in progress.

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**. Extensive progress has been made in the development of design guidelines in Japan (portions will be translated to English), but this work has not started in the US.

Major Research Findings / Accomplishments

The US 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 Connections
   - Bond Stress and Shear Transfer Between Steel and Concrete

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-f 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 - in progress
   - Design Details
   - Economical Floor Plan - Number of Columns
   - Cost Performance - in progress
   - Construction - Not Presented Concrete Mixture, Tests, Casting

4. Initiated study related to high performance materials in CFT.

Future Work / Research Needs

The following are sub-committee recommendations for further work.

1. Connections and System Behavior for **Braced Frames with CFT Columns**. Concentrically and eccentrically braced frames may be best and most economical application of CFT in US practice. These structures and connections details will be quite different from the moment frame connections considered in present research studies. Research is needed on this topic in the US.

2. **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 US.

3. Development of **Design Guidelines** is well underway in Japan, but has yet to be started in the US. Frame testing and shaking table tests to evaluate the interaction of members and connections are very desirable to complete these guidelines.

4. **Column Splice** (economy as well as stress transfer). Column splices may be different for CFT than for ordinary steel structures. This issue is a question of some concern after damage noted in recent earthquakes.

5. **Post Earthquake NDE** (Non-Destructive Evaluation). After an earthquake occurs, it is difficult to evaluate the condition of the concrete inside the tube. US 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 US. Information exchange to US. from Japan is needed in this area.

7. Additional involvement of **consulting engineers** in the theme structure design is very beneficial in the development of practical and economical recommendations and guidelines.

Collaboration / Cooperation

The following summarizes the personal collaboration and cooperation between Japanese and US 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 US 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 are in progress in Japan and will be made available to all US researchers
- Issues of Economy and Practicality of connections and details should be evaluated by engineers and consultants in both US and Japan

All CFT researchers are encouraged to provide summary information on their research projects for the Web page developed for this US-Japan Program. At present some Japanese researchers have submitted their contributions. All US 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 US and Japan in the CFT area during the past year. 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 US-

Japan Program. This will be difficult because of the difference in timing of the Japanese and US efforts, and it is strongly recommended that special funding be available to facilitate this effort.

List of Participants
4th JTCC Joint Technical Sub-Committee Meeting on CFT Systems

Japan Side

Name	Organization	e-mail
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U.S. Side

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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, Cornell University

Summary

The meeting of the RCS committee in Monterey included thirteen participants from Japan, eleven from the United States, and three international visitors. One full day of the meeting was devoted to hearing over twenty presentations summarizing experimental and analytical research, development of design criteria, and recent construction applications of RCS systems. As summarized below, there are seven active projects in the US that are related to the area of RCS structures. While most of the projects in Japan are nearing completion, major efforts are still underway in both the US and Japan to develop design criteria for composite RCS frames and to exchange research findings. Collaboration over the past year has been greatly facilitated by several Japanese researchers who spent extended visits in the US.

List of Participants

Japan Side:

Hiroshi Noguchi, co-chair	Chiba University
Shin-ichi Iizuka	Nishimatsu Corporation
Eiji Ishii	Taisei Corporation
Hidehiko Itadani	BRI (Ohmoto-Gumi Co.)
Hiroshi Kuramoto	BRI
Yasuhiko Masuda	Obayashi Corporation
Mikio Mizuta	Obayashi Corporation
Yasushi Nishimura	Osaka Institute of Technology
Isao Nishiyama	BRI
Noboru Sakaguchi	Shimizu Corporation
Kunio Sugihiri	BRI (Mitsubishi Cons. Co.)
Kazuhiro Uchida	Fujita Corporation
Kenji Yoshimatsu	Kumagai Gumi Co. Ltd.

US Participants:

Gregory Deierlein, co-chair	Cornell University
Hassan Astaneh	Univ. of California, Berkeley
Joe Bracci	Texas A&M University
Dan Frangopol	Univ. of Colorado at Boulder
Roberto Leon	Georgia Tech.
Walter P. Moore Jr	Texas A&M University
Enrico Spacone	Univ. of Colorado at Boulder
Chia-Ming Uang	Univ. of California, San Diego

Don White	Georgia Tech.
James Wight	Univ. of Michigan
Yan Xiao	Univ. of Southern California

Visitors:

J. Bouwkamp	Tech. Univ. of Darmstadt, Germany
Oan Chul Choi	Soongsil Univ., Seoul, Korea
K.C.Tsai	National Taiwan University

Agenda and Summary Of Presentations at Meeting

< **Introductions by sub-committee co-chairs**

Deierlein - Welcome and introduction of US participants.

Noguchi - Introduction of Japanese participants and research progress in Japan

< **Database of RCS test data and design standards**

Sakaguchi, Yoshimatsu, Masuda and IIzuka et al. – Review and evaluation of RCS beam-column connection design models (strength equations, stress transfer models and restoring force characteristics) using data compiled in an electronic database with results from 450 RCS connection tests.

Kuramoto and Deierlein – Summary of work to develop English translations of Japanese database of connection test data and AIJ report with design models for beam-column connections. Reports will be available by the end of 1997.

< **Tests of beam-column connections**

Moore/Bracci - Presentation on tests of RCS beam-column joints with concrete floor slabs. Two tests have been completed and four more are planned for testing within the next year.

Wight - Presentation on test results of five exterior RCS beam-column joints, including one specimen made with fiber reinforced concrete. Three to five dditional tests are being planned to look further into the use of fiber reinforced concrete and the repair/rehabilitation of damaged connections.

Uang - Presentation on plans to test two exterior and two interior RCS joints between steel beam and composite columns with and with steel jackets in the joint region. Some joints will utilize reduced beam section (“dogbone”) concept.

Y. Nishimura - Experiments on stress transfer mechanisms in through beam type joints. Description of the superposition of inner (bearing) and outer panel (torsional) strength. Effect of lateral reinforcement on the joint torsional strength is similar to that described by equations given in the ASCE design guidelines for RCS joints. The shear resisting mechanisms change gradually from an inner panel to an outer panel according to the reinforcing levels in the joint.

H. Itadani and K. Sugihiro - Results of 3D beam-to-column joints tested under bi-directional loading at the BRI. Some discussion on how the 3D-loading path was developed based on the

observed loading orbits observed from the Kobe earthquake. Results to date show that 3D test results are not remarkably different from 2D tests, thus tending to verify the accuracy of existing models developed based on 2D tests.

< **Analysis of beam-column connections**

K. Uchida – Described tests to investigate and analyze bond between steel plates and concrete. Work was conducted while Uchida was in residence at the Univ. of Texas at Austin.

H. Noguchi – Nonlinear 3-D FEM analyses of RCS joints. Results show that the ASCE design equations give conservative joint strengths (approx. 10 to 15% conservative). The FEM analyses utilize interface elements for crack opening/closing and slip between steel plates and concrete at critical locations between the steel beam flanges and surrounding concrete.

< **Test and analysis of RCS frames**

Spacone/Frangopol - Presentation on analytical modeling of frames with composite beams including the effects of material nonlinearity in steel and concrete and bond/slip between the two. Two models were used, one with continuous shear connectors and one with concentrated shear springs elements, and differences between them were described.

Deierlein - Presentation on analysis of RCS frames and review of seismic design issues and criteria. Review of preliminary push over and inelastic time history (dynamic) analyses of RCS frames with comparisons to frame tests conducted by Tokyu Corporation. Future plans include: (1) further verification analyses using other frame tests conducted in Japan, (2) systematic frame analysis/design studies to evaluate seismic design criteria, and (3) development of improved frame analysis/design criteria.

Y. Nishimura- Described a 2D RCS frame test to be conducted in November 1997 at the Osaka Institute of Technology.

K. Uchida/ H. Noguchi – Discussion of 3D FEM Analyses of an RCS frame that include detailed continuum modeling of the beam-columns and connection (joint) regions. Nonlinear bond behavior is shown to be a dominant effect at the boundary of joint and column.

< **Research plans for US beginning in 1997**

Leon/White – Discussion of plans for testing and analyses of composite partially restrained frames consisting of composite beams and steel columns. Some of the testing work will be coordinated with related SAC investigation on bolted frame connections.

Xiao – Discussion of plans for testing encased composite columns emphasizing applications with high strength concrete and shear critical behavior.

Astaneh – Plans for testing composite action in simple shear connections between composite beams and steel columns. These tests are part of the SAC Joint Venture Project and were presented at the US-Japan meeting since they relate to the work of the RCS group.

< **Visitor presentations**

K. C. Tsai (Taiwan) – Described recent tests of eight RCS beam-column joint specimens with through beam type connections and various reinforcing details. Column compression failure was observed near the joint.

Jack Bouwkamp (Tech. Univ. Darmstadt)– Reviewed the design of a 3D composite frame and testing of 2D frame specimens with composite beams and steel columns.

< **Video presentations to introduce recent applications of RCS systems in Japan**

Taisei Corporation - Eiji Ishii introduced an RCS system called the "UNIQUE system" composed of RCS framing in one direction and RC framing in the perpendicular direction. A case study was presented of a four-story building that was built in 16 months.

Kumagai-gumi Corporation - Kenji Yoshimatsu presented two types of RCS systems: one type has rigid joints in one direction and pin joint in the perpendicular direction, and the second type is constructed using steel erection columns. Case studies were presented on each system, the two-story Naruto shopping center and the Higashitotsuka shopping center.

< **Design guidelines**

I. Nishiyama/ H. Itadani et al. – Overview of a new initiative of the Ministry of Construction to develop design guidelines that permit the use of both current seismic practice and new performance-based methods.

Summary Of Progress And Near Term Plans

Beam-Column Connection Testing: Including work in-progress, seventy-one RCS beam-column joint specimens will be completed as part of the US-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 US. In spite of the large number of previous tests, those conducted as part of the US-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 should be more emphasis on sharing/exchange and critical review of test reports/papers between the Japanese and US researchers. An important mechanism for such sharing is the electronic database of connection test data that has been compiled by the BCS in Japan and will soon be available to researchers in the US from Cornell University. During the next year, US and Japanese researchers should incorporate new test data into this common database.

Member Testing: To date there has been little or no member testing done as part of the US-Japan initiative for RCS structures. However, Xiao and Anderson (of USC) have plans to conduct tests of encased composite SRC columns made with high strength concrete and to investigate shear-critical behavior.

Frame Testing: RCS frame tests have been conducted in Japan by the Tokyu Corporation (1 test), the Nishimatsu Corporation (2 tests), and the Okumura Corporation. One additional RCS frame test will soon be completed at the Osaka Institute of Technology under the direction of Prof. Nishimura. No tests have been conducted or are currently planned in the US.

Analysis Model Development/Verification: The following is a summary of efforts to develop, implement, and test new analysis formations for the inelastic analysis and design of RCS systems and components:

- University of Colorado – Model for composite beams including slip and partial composite action
- Cornell University – Interactive program 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 installed and is being used in cooperative research with the Steel Structures Development Center of the Nippon Steel Corporation.
- University of Chiba 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.

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 Cornell University are currently developing trial designs for six, twelve, and twenty-four story RCS theme structures based on the 1997 NEHRP Recommended Provisions for the seismic design of composite structures. Designs will be developed and analyzed for various levels of seismicity. Researchers at Georgia Tech will undertake related work for composite PR frames. Other groups in the US 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.

Design Models and Criteria: The latest 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 expected to be complete in March 1998. It is hoped that Kuramoto (of the BRI) can develop an English translation of this document with the editorial assistance of US researchers.

In the US, design criteria for RCS frames are available from several sources. The 1997 editions of the NEHRP Recommended Provisions and the AISC Seismic Provisions (Part II) include general seismic loading and design/detailing criteria for composite structures. 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. It is anticipated that US researchers involved in the US-Japan Program will participate in forthcoming initiatives within ASCE, AISC, and ACI to develop improved and more comprehensive design criteria for RCS frames.

Recommendation for Future Work

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 (listed roughly in order of priority):

- 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.

- Testing of Full Scale RCS Beam-Column Joint – Nearly all of the 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.

- 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.

- Development Performance Based Design – Experimental and analytical research is needed to support the development of performance based design criteria for RCS structures.

- 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.

- 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.

- RCS Frame Tests - While several RCS frame tests have been conducted in Japan, these frames are not necessarily representative of practice in the US. Multi-story, multi-bay RCS frame tests designed following US criteria and standards may provide valuable insight and verification of overall system behavior.

- 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. However, this topic is of lesser concern in the US where RCS frames are often designed as planar systems.

Research Dissemination and Collaboration

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

〈 **Conferences:** Sessions that focus on the US-Japan program are currently scheduled for the following upcoming conferences:

- SEWC ’98 (San Francisco) – Three or four sessions are planned
- -ACI- March ’98 (Houston) - One session is planned

Other future conferences where it may be useful to organize sessions include the following:

- -ASCE Congress ’99 (New Orleans)
- -ASCCS-Los Angeles, Spring 2000
- -ACI-Nov. ’98 (Los Angeles: Constructability for Seismic Regions)
- -EERI-Annual meeting ’99 or 2000
- -WCEE 12-New Zealand 2000
- -AISC Annual Conf.- ’99 or 2000

〈 **Journals:** It is suggested a dedicated issue on the US-Japan Program be published in one or more engineering journals over the next few years. A target submission date of January 1999 would be a good time to summarize Japanese research that has been completed and US research that is near completion. The following is a suggestion of possible journals for publication: Engineering Structures, Journal of Const. Steel Research, EERI Spectra, ASCE Sruct. Journal, ACI SP, Earthquake Engineering and Structural Dynamics, AIJ Struct. Div. Journal (in Japanese with summary in English).

〈 **Web site –** US 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.

〈 **Collaboration: Personal Exchange –** During the past year, several Japanese researchers were in residence in the US (H. Kuramoto at Cornell University from Oct. 1, 1996 to Oct. 1, 1997; Noguchi/ Uchida at the University of Texas from summer 1997 until Jan. 1998). In the future, there is the possibility that other BRI staff may arrange extended study leaves to the US. Also, Deierlein is investigating opportunities for a Cornell Ph.D. student to spend time at the BRI in Japan.

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

List of Participants

Japan-Side	US-Side
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T. Kabeyasawa, Co-Chair	K. Mosalam
T. Kei	V. Mujumdar
J. Kobayashi	A. Schultz
Y. Matsushima	B. Shahrooz
S. Sasaki	B. Shing
M. Teshigawara	J. Wallace
A. Wada	L. Wyllie

See Attachment A for addresses of participants.

Review of Recommendations from Second and Third JTCC Meetings

The specific recommendations and findings of the Second and Third JTCC Meetings were reviewed and discussed. Many of these recommendations were reaffirmed, since the work on the US side is still in its infancy and no new HWS projects were added in Year 3 funding. The results of these discussions are summarized as follows:

Interaction of Systems

Although several important investigations were conducted to assess the interaction of components in hybrid systems, additional work is needed to 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, the accuracy and reliability of such analyses are uncertain at the moment. As well, the availability of robust computer programs and models limits the scope of the potential analytical studies. Additional work is needed to compare experimental data with results obtained using different modeling idealizations and numerical approaches.

In particular, many of the complexities exhibited by coupled wall systems come from the nonlinear behavior of the coupling beams. However, the effects of the floor slab on the behavior of the coupling beams is thought to be significant and this may change the conclusions drawn from the test results and analyses. 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, as well as some of the issues noted in the following items.

It was believed to be desirable to conduct analytical investigations of hybrid wall systems to:

- better identify the optimal degree of coupling in between coupled shear walls,
- to establish design oriented methods for estimating the variation of M, N and V in walls.
- to establish the expected number and magnitude of cycles in coupling girders.
- to 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: Need to consider cases with higher axial loads representative of those that may be encountered in practice in the US for tall core-wall buildings. Analytical models for walls are improving, but remain to be quite primitive relative to the actual cyclic behavior observed. Improved analytical idealizations, numerical procedures, and constitutive models are needed.

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 US. 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 US. Additional work will be needed from the US perspective to consider the wide range of parameters that can be envisioned in design. The studies should be at large scale and use realistic materials. The influence of variable axial load on the behavior of the wall should also be addressed.

Behavior of Coupling Girders

Connections to Walls: Some work done in the US and Japan. Issues related to the effect of slabs, and local detailing, need additional investigations. Work is currently underway in the US related to the connection on other 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.

Reinforced Concrete beams: Question were raised in discussions 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.

Slab effects: Although results of detailed work on this topic conducted in Japan indicates that the influence of floor slabs on the behavior and distribution of internal stresses in coupled wall systems is not significant, the group remained concerned about this issue. Additional work on this is recommended to re-evaluate the BRI test as well as to conduct more detailed analytical studies. Well designed, experiments may be helpful in further evaluating this issue.

Energy dissipation devices: While this is an appealing concept, there was not a feeling that this was a high priority. As well, studies of this type appear to fall into the RFI area.

Repair of coupling girders: Repair of damaged girders and members was also mentioned as a topic that should be considered since performance based design methods were being developed. Because of these concerns, the selection of details and materials should be done considering the ease of repair. Consideration of the spalling of the concrete and its threat as a falling hazard also need to be considered as coupling beams are often over emergency exits (practical methods for preventing spalling, such as fiber reinforced

concrete or a simple net could be used).

Foundation Effects

Very little work has been done on foundations, yet studies to date indicate that the flexibility of the foundation may increase the plastic rotation demands on the coupling girders, reduce deformation demands on the walls, and reduce the increase in girder axial load caused by foundation restraint of the transverse displacement between the walls. Analytical studies should be considered to more realistically assess the influence of the foundation on the overall behavior and performance of the system.

Analysis Methods:

This is an area of high need. 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. The committee agreed that this was still an area of high need. 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). May need to gather available information. In Japan, if dynamic analysis is done, it is usually nonlinear dynamic analysis.

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).

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). Issues related to performance based design criteria need additional work. Much work remains to be done to design and evaluate a theme structures designed using US procedures and criteria.

Evaluation of constructability: Neither country has systematically considered issues related to constructability of hybrid wall systems. These issues remain to be addressed.

Design Methods:

Performance Based design. Some work has been done in Japan derived from earlier work contained in Vision 2000. 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 US, although details may have to wait for the completion of the experimental studies.

Methods: Methods need to be devised for simplified design of walls and frame. This is being addressed in one of the US projects, but on a limited scale. Additional work is needed.

R_W and D_S values: 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.

	1997	1998	1999	2000
Japanese-side	Design Methods	Monitoring US activities	Monitoring US activities	_
US-Side	Testing	Testing and analysis	Analysis and Design	Wrap-up

Summary of Current Work

Brief presentations were made by all present who have conducted or are planning to carry out investigations on Hybrid Wall Systems. Much discussion took place related to each presentation. These presentations included:

J. Wallace

Tests on Walls with Steel Boundary Columns

Work to date has focused on refining the experimental program to best address design, construction, and behavior issues that have been identified. A meeting was held at the April 1997 ACI meeting in Seattle to discuss these issues. Prior design and construction examples, presence or lack of steel beams in the SRC walls, and the use of construction bracing were discussed. To improve constructability, steel beams should not be extended into the SRC wall and bracing within or outside of the wall may be necessary. Main issues to be addressed include: wall boundary column size and orientation, wall shear stress at flexural capacity, anchorage of wall horizontal steel, and confinement at wall boundary and web. Tests to be conducted on rectangular and T-shaped walls. Preliminary schedule is for testing in the Summer and Fall of 1998.

Needs: Testing should address core wall issues and consider the importance of variable axial load and the variation of wall stiffness under tension and compression.

B. Shahrooz

Tests and analyses of coupled walls with composite girders

Modeling of composite coupling beams and RC walls was presented. Using the identified parameters, the response o f a prototype structure was evaluated to understand the expected level of shear defomation in composite coupling beams. Design models have been developed, and are being distributed to the engineering community.

Needs: The importance of axial load within the coupling girder on the behavior of the composite slab and girder and of the embedment of the coupling girder in the wall was not certain. Additional work may be desired with more complex test specimens or analysis models capable of simulating this behavior.

Y. Matsushima

Seismic Tests and Analyses of a 12-story T-shaped Coupled Wall

Tests of a one-third scale twelve story coupled wall system were conducted at BRI under lateral and vertical loads simulating those used in design in Japan. Tests were conducted to drifts of about 1/25. Buckling of the girder rebars and spalling occurred at drifts near 1/50. An analysis of the specimen was carried out using a multi-spring model for the walls and coupling girders. Reasonable correlation between analytical and experimental results were obtained with the fiber model, including the transfer of shear from the tension to compression wall. The coupling girders elongated as a result of cyclic plastic excursions resulting in an increasing compression load in the coupling girders.

An analytical study was carried out to evaluate the distribution of shear force in the coupled wall system. A truss model was tried; however, it did not simulate the residual compressive force in the coupling beams and could not replicate the observed shear distribution between the wall piers. A multiple-spring model provided more reasonable results by predicting the influence of axial load on wall stiffness, wedge action of coupling beams, and residual compressive coupling beam axial load.

Analytical studies were conducted to address the importance of the floor slab on the behavior of the specimen. Results of these studies suggest that the influence of the floor slab is not significant.

Needs: Analytical investigations would be desirable to assess the likelihood that soil and foundation flexibility could reduce the axial forces developing in the girders. Additional work is needed to address some of the modeling issues for floor slabs and to identify some of the discrepancies noted in the studies conducted to date. The effect of higher mode effects on the number of plastic excursions should be investigated, including the effect of structural period and wall configuration. Comparisons of single component, analytical results obtained with multi-spring and fiber models would be desirable.

A. Schultz

Steel Moment Frames with Composite Infilled Frames.

This research is focused on shorter buildings (10-20 stories, and maybe shorter) 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. Design of 6- and 10-story prototype buildings was presented. For the 15-story building, drift limits require rather large columns. This result is attributed to the “theme” structure, which does not bring out the attributes of the system. For this project, alternatives to the theme building will be considered. Results of FEM studies indicate very large tensile forces on the beam studs; however, it is believed that the large values are due to modeling assumptions and may not necessarily correspond to the actual values. The model will be modified based on experimental data which will be generated as part of this research. Results from shear connector tests were presented. 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. Future tests will concentrate on cyclic behavior

of shear connectors before final details of the test specimens are decided.

Needs: Behavior of studs for cyclic loads. Evaluation of alternative structural configurations to bring out the benefits of the structural system.

T. Kabeyasawa — Design of RC Walls in Hybrid Wall Systems

A new wall macro element was presented. The model involves nonlinear axial springs at the wall edges and a nonlinear panel element. Finite element concepts are used for the panel element. Very good correlation for isolated and coupled walls is possible by the new modeling technique provided the level of axial load and shear is not too large. Simulation of concrete shear response as a funtion of wall axial load, and estimation of tangent stiffness pose difficulties.

Needs Further development and comparison with additional experimental data.

T. Kabeyasawa — Dynamic Magnification of Wall Shear

A method to predict wall shear under dynamic loads was discussed. The method involves superposition of the shear force as obtained from pushover analysis under lateral loads which are distributed according to the first mode, and higher mode shears obtained from a linear acceleration response spectrum.

Needs:

B. Shahrooz — Diaphragm to Wall Connections

Connection of diaphragms to RC walls is being studied. A prototype structure along with preliminary analyses were presented. The parametric studies do not suggest any advantages for moment connections for steel floor beams to exterior columns. Therefore, the project will focus on use of simple connections. These connections will be selected to address both floor beam connections as well as full-story truss type connections. Four approximately _ - scale specimens are being designed and will be tested. The specimens will include a portion of an I-shaped wall, with a beam and slab connection. Cracking of the wall in the connection region and the type of loading will be the main variables.

Needs: Input on the final specimen design from other researchers and the design community.

M. Teshigawara — Seismic Design Guidelines for Hybrid Wall Systems

A proposed draft for performance-based design of hybrid wall systems was presented. 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.

Needs: The sensitivity of design capacity values to changes in configuration and structural geometry needed to be assessed. Issues such as the repairability of coupling girders and walls, need to be assessed for limit states related to criteria focusing on continued occupancy following repair.

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:

- A 12-story coupled wall specimen with T-shaped reinforced concrete walls was tested at BRI - good inelastic behavior was achieved, demonstrating the desirable features of the system. The influence of the floor slab on the system response was investigated. Findings indicate that this influence may not be as significant as thought, although additional work is needed.
- Additional work has been conducted to understand the complex nonlinear redistribution of internal forces was identified in the tests of coupled wall systems.
- Tests of coupling girder tests were completed using RC girders as well as ones using steel and composite girders. Guidelines for design were 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.

Regarding Design:

- More freedom in architectural design possible by concentrating walls in core
- Hybrid wall systems are good at controlling lateral displacements and providing good energy dissipation.
- Alternative schemes for construction bracing may improve constructibility of SRC core walls.

Future Research Needs and Priorities

A wide variety of issues requiring additional research and development were identified. In summary, areas of high priority included:

1. Improved analysis procedures - more accurate and reliable models and methods are needed to help assess behavior of elements and systems.
2. Identification of the effects of floor slabs on the behavior of coupling girders as well as of the overall system, including the influence of diaphragm flexibility.
3. Additional experimental investigations are needed, especially in the US, to assess a wider variety of design parameters than being considered at present (such as axial load, shear, local details, confinement, basement walls, etc.).
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, near-fault ground motions, and so on.
6. Additional analytical and experimental investigations of the interaction of core walls with perimeter frames.
7. Development and assessment of simplified design and analysis methods, including an assessment of static pushover and dynamic analysis procedures.
8. Development of performance-based design methods.
9. The interaction of steel and concrete elements at interfaces with welded, headed anchor studs or other anchors is needed for cyclic loads.

Recommendations and Plans

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

Future Work:
Greater emphasis will be placed on dissemination of the findings of the project. The Japan side will consider providing seminar to a limited audience of Japanese professional engineers participating in the Composite and Hybrid System Program. US side will organize along with Japanese investigators a session on Hybrid systems at the First World Structural Engineering Congress to be held in San Francisco in 1998.
In addition, the Japanese-side wishes to continue to meet once a year to follow up on and monitor activities in the US on test results and efforts to develop of design methods. In particular, interest exists in Japan related to studies of wall behavior (with for instance more realistic axial loads), coupled girder with slabs, setting performance-based design response parameter, and practical design methods.

The American-side will be initiating a significant testing and analysis program as outlined above under presentations on hybrid walls and wall to slab connections. Additional experimental and analytical investigations are needed in the coming year to supplement existing projects. In addition, efforts are needed on the US side to design and evaluate the performance and constructability of the theme structure.

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 to maximize the benefits.

Loading Histories and ground motions:
Sets of ground motions are being generated for several US sites as part of the SAC Steel Project. These will be 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 US. This information will be distributed to the US and Japanese participants for their consideration. The US participants initiating testing programs are encouraged to coordinate the selection of loading histories and instrumentation protocols.

Collaboration and cooperation:
Considerable opportunity (need) exists for coordination on the US-side related to cyclic shear stud/concrete interface tests and in planning hybrid wall tests.

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: Prof. B. Shahrooz at BRI for 2 months.

Attachment A: Roster of Participants

Joint Technical Sub-Committee Meeting on Hybrid Wall Systems

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

List of Participants

Japan - Side	U.S. - Side
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A. Mikame	N. Krstulovic-Opara
T. Nagao	
A. Tanaka	
M. Watabe	
H. Yamanouchi	

Research Activity

Research activities in the RFI group are concentrated in the area of advanced cementitious composites including:

1) **Fiber Reinforced Polymer** (FRP) composites,
2) **Fiber Reinforced Concretes** (FRCs) that exhibit improved ductility and/or high strength, light weight and improved ductility (e.g., steel fiber FRCs or High-Strength Lightweight-Aggregate FRCs, HS-LWA FRC, with compressive strengths of 7,000 - 12,000 psi at 3-4% strain, reaching more than 1% of strain without significant decrease in the load capacity),
3) **High-Performance FRCs** (HPFRCs) exhibiting either **(a)** very high strength and ductility in both tension and compression [e.g., steel fiber Slurry Infiltrated Fiber Concrete - SIFCON and recycled stainless-steel Slurry Infiltrated Mat Concrete - SIMCON, with (I) tensile strengths of 2,500 psi at 1-2% strain, and reaching more than 3 % of strain without a significant decrease in load capacity, (ii) compressive strengths of 9,000-17,000 psi at 2-3% strain, and reaching more than 10 % of strain while still maintaining significant load capacity], or **(b)** very high ductility [e.g., FRC made with polyvinyl alcohol (PVA) fibers called PVA-Engineered Cementitious Composite, PVA-ECC, which reaches 6 % of strain at (maximum) stress of 500 psi in tension and 5% of strain at 4,300 psi stress in compression],
4) **High Performance Concrete** (HPC) elements that are very lightweight and ductile (e.g., having specific gravity between 1.2 and 1.6, and reaching 8,700 psi at 4% of strain).

Specific topics include (**a**) development of advanced composites, and/or (**b**) development of structural systems made by the selective use of these composites. Covered topics are very much in agreement with the priorities and recommendations made during previous JTCC meetings. Results indicate that the selective use of advanced composites provides excellent seismic performance and can significantly minimize or eliminate the need for conventional reinforcement in structural members.

The group felt that an integrated, i.e., "holistic" approach to the development of both advanced composites and 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.

The schedule of ongoing research activities is shown in Table 1. A list of specific presentations on RFI conducted during the meeting is shown in Table 2.

Topic	Country	Present Status (see Figure 1)	Expected Results by March 1998	Goal for September 2,000 (end of the U.S. Program)
FRP	Japan	Phase III	Guidelines	
	U.S. (outside US-J CHS)	Phase II / III	Guidelines (American Concrete Institute - State-of-the-Art Report)	
FRC	Japan	Phase II		Complete Phase III and provide guidelines
	U.S.			
Lightweight Concrete	Japan	Phase I	Phase II	Complete Phase III and provide guidelines
	U.S. (High Strength Lightweight FRC)			
High-Strength, Ductile Plain Concrete	Japan	Phase I	Phase II	Complete Phase III and provide guidelines
	U.S.	N.A.	N.A.	N.A.

Table 1: Schedule of ongoing research activities.

Presenter	Paper Authors	Paper Title	Topics Covered
A. Mikame	A. Tanaka, Y. Matsuzaki, A. Mikame, and H. Fukuyama	**Japanese Research Activities on RFI**	lightweight concrete, ductile concrete, FRC, FRP-mesh reinforced concrete, FRP sheets for seismic retrofit
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 high-strength lightweight FRC
J. K. Wight (presented at the RCS Technical Sub-Committee Session)	J. K. Wight	**Behavior of RCS Connections Subjected to Seismic Loading**	FRC in RCS joints
(paper only)	V. C. Li	**Engineered Cementitious Composites (ECC) for Ductile Reinforced Concrete Elements**	PVA-ECC for ductile elements

Table 2: List of presented papers.

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 (i.e., HPFRCs, FRCs, and FRPs) in critical regions of both current as well as new structural systems. Examples include selective use of these composites in joints, connectors, dampers, etc.

2) novel structural members and systems made by encasing steel elements into FRC,
3) investigation of (a) reversed cyclic behavior of advanced composites, and (b) development of procedures for predicting behavior of composite structural members and sub-assemblages under reversed cyclic loading, using information obtained in (a),
4) cost-effectiveness studies of the structural systems made using advanced composites,
5) fire-resistance studies of the structural systems made using advanced composites,
6) development of new HPFRCs with even higher strengths and/or ductility in both compression and tension,
7) manufacturing and development of high-ductility non-metallic FRP 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.
2) Conduct further joint development and full-frame testing of FRC encased steel joist systems, and
3) further investigate applications of ductile cementitious composites.

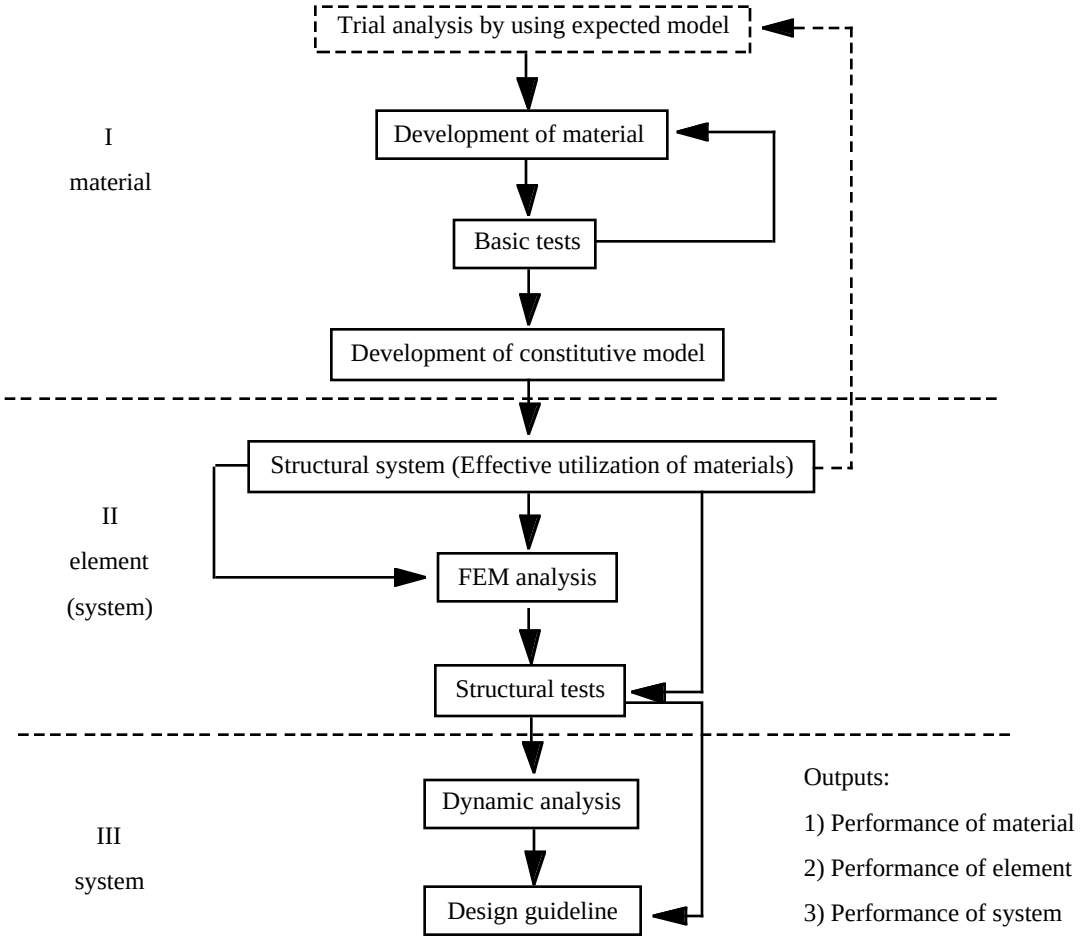

Figure 1: Flow-chart of the suggested "holistic" approach to material and (structural) system development.

Attachment A: Roster of Participants

Joint Techinal Sub-Committee Meeting on Research for Innovation

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