UNITED STATES/NEW ZEALAND/JAPAN/CHINA COLLABORATIVE RESEARCH PROJECT ON THE SEISMIC DESIGN OF REINFORCED CONCRETE BEAM-COLUMN-SLAB JOINTS

General Report on the Project R. Park*

INTRODUCTION

A United States/New Zealand/Japan/China collaborative research project on the "Seismic Design of Reinforced Beam-Column-Slab Joints" has been in progress during the last five years. This collaborative research project was initiated because there are currently a number of differences between the approaches used for the seismic design of reinforced concrete beam-column-slab joints in building frames in earthquake regions of the world. For example, New Zealand design procedures are more conservative than United States procedures for some joint configurations and are less conservative than United States procedures for other joint configurations. Japan and China have written new building codes for the seismic design of multistorey reinforced concrete moment resisting frames and are continuing to review the possible approaches. The major differences between the current design procedures of the various countries are in the quantities of transverse reinforcement required in joint cores for shear and confinement, and in the maximum allowable bar diameters permitted for longitudinal reinforcement passing through joint cores to satisfy bond requirements. Other significant differences in the design procedures also exist.

In the early 1980s the Applied Technology Council of the United States set up a project to review the test data and design approaches for reinforced concrete beam-column joints of various countries (ATC-08). The members of the review committee were mainly consulting engineers. In 1983 Mr. J.L. Stratta, chairman of the ATC review committee, suggested to Professor R. Park of the University of Canterbury and to Professor J.O. Jirsa of the University of Texas at Austin that United States and New Zealand research engineers should come together in a project on this problem. Professor H. Aoyama of the University of Tokyo, also expressed interest in such a project.

The collaborative research project was set up in 1984 with the aims of (1) to achieve agreement on the mechanisms of behaviour of beam-column-slab joints of reinforced concrete building frames during earthquake loading and (2) to develop more unified design procedures for reinforced concrete buildings frames for earthquake resistance. These aims were to be achieved by carefully coordinated experimental testing and by discussion at meetings. The principal investigators were to be from the University of Canterbury, the University of Texas at Austin and the University of Tokyo.

THE FIRST AND SECOND MEETINGS AND THE AGREED TEST PROGRAMME

Meetings of principal investigators of the United States, New Zealand and Japan, and other participants, were held in California in July 1984 and in Tokyo in May 1985. The meetings were to review design codes and research in the United States, New Zealand and Japan and to coordinate the design, instrumentation and simulated seismic loading history of beam-column-slab specimens which would be tested to investigate the differences between the design approaches of the three countries.

As a result of the two meetings it was agreed that the structural testing laboratories at the University of Canterbury, the University of Texas at Austin, and the University of Tokyo would each construct three reinforced concrete beam-column-slab assemblies, designed according to the code procedure of their country, for testing under the same simulated seismic loading. The assemblies would be of the following types:

- Specimen 1 : One-way interior beam-column-slab assembly
- Specimen 2 : Two-way interior beam-column-slab assembly
- Specimen 3 : Two-way exterior beam-column-slab assembly.

Each assembly represents a particular portion of a building structure in the region of the junction of beams, columns, and slab floor. The three assemblies tested at the University of Canterbury and at the University of Texas at Austin are full-scale, and at the University of Tokyo the three assemblies are one-half scale. The overall dimensions of the full-scale assemblies are in the order of 3.5 m high and a maximum of 3.5 m x 3.5 m in the

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horizontal directions. The columns are approximately 600 mm square and the beams approximately 550 mm x 400 mm. Photographs of the University of Canterbury assemblies, at various stages of construction and testing, are shown in the attached figures.

The results of the tests will be of particular interest since the specimens are all designed for the same seismic loading and only differ in that the reinforcement is detailed according to the code of the country where the tests are being conducted. The specimens are subjected to the same simulated seismic loading history in the tests. This enables the performance of structures designed according to the codes of the countries to be compared on a rational basis. Some additional specimens are also being tested in some countries.

In 1985 the China Academy of Building Research in Beijing and Tongji University in Shanghai requested that China be included in the project and will test reinforced concrete beam-column-slab assemblies designed according to the new Chinese code. Hence the project now formally involves four countries, which represents significant international collaboration.

The principal investigators for New Zealand are Professors T. Paulay and R. Park of the University of Canterbury. A PhD student, Mr. Cheung P.C., has been conducting the tests. Testing of the three specimens at the University of Canterbury began in mid-1986 and was completed in 1988.

Financial support for the tests at the University of Canterbury has been provided by the Building Research Association of New Zealand (\$33,900), the Ministry of Works and Development (\$33,500), the University Grants Committee (\$9,000) and the University of Canterbury. The full size of the test specimens, the large loading rig, the significant technician time involved, and the study award for the PhD student, have required this extensive support from outside agencies.

THE THIRD MEETING

During 10-12 August 1987 the third meeting of the principal investigators from the four countries, and other participants, was held at the University of Canterbury. The New Zealand participants at the meeting were Professors R. Park and T. Paulay of the University of Canterbury, Dr. R.C. Fenwick and Mr. L.M. Megget of the University of Auckland, Mr. G.R. McKay of the Ministry of Works and Development, and Dr. A.J. O'Leary of Morrison Cooper and Partners. Nine participants from the other three countries were present. At the meeting progress reports were presented by the principal investigators of all four countries. Discussion at the meeting concentrated on the results of tests conducted to date, the theoretical aspects of the mechanisms of shear and bond transfer in beam-column-slab joints, the expected function and performance of reinforced concrete beam-column-slab joints during earthquake loading including aspects of strength and deformations due to shear

and bond transfer characteristics, and problems of design and construction of beam-column-slab joints in practice. One main issue, on which international agreement is difficult to reach, is the definition of "acceptable performance". Code requirements can be made less stringent if a poorer performance of a structure during a major earthquake is judged to be acceptable. Some countries are prepared to accept a poorer performance than others.

THE FOURTH (FINAL) MEETING

Not all tests were completed in time for the results to be available at the third meeting. Also a further meeting was required to discuss the possible modifications to current seismic design codes for beam-column-slab joints in the four countries which could result from the findings. Hence a fourth (final) meeting on the project was held in Honolulu, Hawaii, during 24-26 May 1989. The New Zealand participants were Professors R. Park and T. Paulay of the University of Canterbury and Dr. D.C. Hopkins of KRTA Ltd. The list of topics discussed and the full list of participants are shown in the Appendix. No representatives from China were able to be present.

Again at the Fourth Meeting there was difficulty in defining "acceptable performance" to judge the results of the test specimens. Each nation was of the view that the results of their tests indicated satisfactory behaviour. Hence there are still differences in opinions regarding the quantity of transverse reinforcement required in beam-column joint cores and the limitations of bar diameters necessary to ensure adequate bond performance. Details of the technical discussion are highlighted in the accompanying report on the meeting by Dr. D.C. Hopkins.

It is apparent that some relaxation of the New Zealand code (NZS 3101:1982) requirements for shear and bond in beam-column joint cores could be permitted. The current provisions of NZS 3101 were written a decade ago and the significant additional testing which has been conducted since that time indicates that those requirements could be made less severe.

In particular the large amount of testing which has been conducted in Japan during the last 5 years, and the associated well coordinated committee work, is extremely impressive. A wealth of data is now available from Japan which can be used to assess the effects of the main variables in beam-column joint design.

The seminar was extremely valuable in providing a large amount of information from the three countries involved. The opportunity to exchange views and to evaluate the test results of the three countries will result in a narrowing of the gaps between the design procedures of the three countries. The project has given the participants a much better insight into the design philosophies underlying the three

national codes. In working together in a cooperative effort much more has been gained, and gained more rapidly, than would have been accomplished by working individually or by efforts in each country being carried out independently.

Similar cooperative efforts should continue. Support is needed not only to conduct the experimental programs, but to also permit those involved to meet regularly to plan, assess and monitor the results.

The considerable amount of information gathered from the four countries as a result of the project will lead to better understanding of, and more unified design procedures for, reinforced concrete building frames for earthquake resistance.

It was agreed that summary papers of the project will be presented at two 3 hour sessions at the Fall Convention of the American Concrete Institute to be held in San Diego during 29 October - 3 November 1989. These papers will be printed in a Special Publication Volume of the ACI. It was also suggested that Pacific Rim countries should attempt to write a unified model code for the seismic design of reinforced concrete structures.

ACKNOWLEDGEMENTS

The financial assistance provided by the NZ National Society for Earthquake Engineering to enable R. Park, T. Paulay and D.C. Hopkins to attend the seminar is gratefully acknowledged.

APPENDIX - 4th MEETING, HONOLULU

Seminar on Seismic Design of Reinforced Concrete Beam-Column-Slab Joints

United States

J.O. Jirsa
A.J. Durrani
C.S. Kopczynski
J.P. Moehle
M.A. Sozen
D.A. Strand
J.K. Wight
L.A. Wyllie
P. Gergeley
M.E. Kreger
R. Leon
C. French

New Zealand

R. Park
T. Paulay
D.C. Hopkins

Japan

H. Aoyama
O. Joh
T. Kaku
K. Minami
S. Morita
H. Noguchi
S. Otani
H. Hatamoto
T. Ichinose
K. Katayama
J. Kobayashi
Y. Kurose
T. Nagashima
K. Yoshioka

REINFORCED CONCRETE ONE-WAY INTERIOR
BEAM-COLUMN-SLAB:
ASSEMBLY AT END OF TEST

SLAB REINFORCEMENT AND FORMWORK FOR
REINFORCED CONCRETE TWO-WAY
INTERIOR BEAM-COLUMN-SLAB ASSEMBLY

REINFORCED CONCRETE TWO-WAY EXTERIOR BEAM-
COLUMN-SLAB:
ASSEMBLY AT END OF TEST

Report on the Fourth Meeting held in Honolulu, May 24-26, 1989

D.C. Hopkins*

This further meeting on the Collaborative Research Project was attended by 30 engineers from US, Japan and New Zealand. Over 30 short papers were presented during the three days, covering research, design and construction aspects. The small number attending allowed a free exchange of ideas between parties.

Although the main focus of the Meeting was beam-column joints, the presentations and discussion spilt over into design philosophies and future research needs.

Highlights from the writer's point of view were:

1. The presence of top researchers from all three countries, representatives of the five major construction companies in Japan, and leading designers from the US.
2. Clear evidence that Japan has carried out an enormous amount of research in earthquake engineering in the last few years, each construction company having large research departments.
3. The differences in underlying philosophy and approach between all countries. This forum showed very clearly that each country conducts its research and approaches design in the framework of its own historical approach. Although there is much in common, the differences may be summarised as follows:

NZ uses low forces requiring high ductility demands and rigorous analysis.

USA uses low forces, implying high ductility demands but a more pragmatic approach is taken in formulating design requirements.

Japan uses higher forces, requiring considerably less ductility. Even so analysis and design requirements appear thorough.

All countries have similar drift limitations (around 1%) in their structures, and use similar shaped response spectra.

All countries have now some form of capacity design, NZ having by far the most exacting requirements.

4. In the case of beam-column joints, these differences are evident in the various criteria for acceptable performance. New Zealand relates performance to subframe ductility demands, thus automatically accounting for varying beam and column stiffness. US researchers relate results to drift which makes direct comparison with NZ results difficult. Japan relates results to drift but generally 1% drift corresponds to a displacement ductility of approximately 1.5.
 5. Mechanisms of force transfer within the joint are generally agreed, although the relative contributions of strut action and truss action vary. Close attention was paid to the effectiveness of bond on the tension steel through the joint, including the effects of axial load. Generally axial load had a relatively small effect.
 6. The influence of confining steel and beams at right angles was debated strongly. Here again comparisons were difficult because of the different approaches. It seemed possible that the more demand placed on the joint, the more important confining steel may become. The same may apply to joint shear reinforcement.
- Japan's larger design forces produce wider columns which eases bond problems in the joints.
7. The influence of slabs and slab steel on the performance of the joint was considered by a number of researchers using both theory and tests. This is a complex subject involving the development of forces by beam torsion and horizontal bending. Opinions differed as to the reliability of available extra strength and local damage. While simple effective width formulae may not identify all the various mechanisms and complexities, they will suffice for almost all situations, especially in NZ where lightly reinforced toppings are common.
 8. Bi-axial Effects
- Testing was done in all three countries on sub-assemblies with orthogonal beams intersecting at the joint. Performance was generally good and the influence of one beam upon the joint behaviour in the orthogonal direction was not significantly detrimental.
9. The behaviour of eccentric beam-column joints was explored, even though it is generally accepted that these are undesirable. Simple first principle procedures are used by designers applying normal rules but only the common web area was in calculating nominal shear stress.
 10. One researcher had looked at unreinforced joints used in many New York buildings. Good results were obtained giving considerable hope for such joints in older NZ buildings. Research in New Zealand on this subject

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would be worthwhile with the object of deriving methods for appraising existing buildings.

11. The use of precast concrete in NZ and Japan was described, Japanese practices being remarkably similar to those used in NZ. Testing of the various joints and systems is clearly well advanced, far outstripping NZ's efforts to date. We can learn much from their research and construction practice.

12. Repairs and strengthening of existing structures received some attention. A US researcher reported on the effectiveness of basketing type repair of columns (corner bars plus hoops plus 100 mm perimeter concrete). Tests showed it was very effective for the very flexible beam-column assembly studied.

The Japanese reported on tests on a specimen which had been put through the normal loading regime, carefully grouted up, and retested. Conclusion? - performance carried on where it had left off even though penetration of the epoxy grout was excellent.

13. The use of high strength concrete and steel was addressed by some authors. This raised a number of difficulties including the validity of extrapolation of formulae, and the practicalities of having high strength concrete in the beam-column joints but not in the floors. (One example of the specification of different coloured concrete for different strengths was quoted).

14. Future Research Topics Identified Included
 - High Strength Construction
 - Precast Concrete Construction
 - Structural Walls
 - Columns
 - Shear and Bond
 - Existing Buildings
 - Ductility vs Drift
 - Overall Response and Redundancies
 - Acceptable Performance Criteria for Joints
 - Development of a Model Code for the Pacific Rim.

CONCLUSION

We in New Zealand can learn from continuing dialogue with these countries not only by comparison of detailed research results and construction practices, but by questioning our own basic approaches in relation to theirs. Even if we do not change our codes, our buildings will be the better for such comparisons.

There appears to be room for some relaxation in New Zealand detailing requirements, and a growing need to review our force, ductility and drift limits to place more emphasis on protection of the building fabric.

ACKNOWLEDGEMENT

Financial assistance from NZNSEE to attend the Seminar is gratefully acknowledged.

PARTICIPANTS AT THE 4TH MEETING OF THE UNITED STATES/NEW ZEALAND
/JAPAN/CHINA COLLABORATIVE RESEARCH PROJECT, MAY 1989

In earthquake engineering there are two factions:

The Loaders - those on Loading Committees

The Jointers - those who do research into beam-column joints

Communication between the two is desirable, hence a theme song,

ADDENDUM

At the recent 4th meeting there was apparently both time and inspiration for one of the three former Presidents of the Society representing New Zealand to pen the lines in adjacent column. No indication has been given yet as to whether the lines were sung (and if so to what tune) or were merely recited.

The Editor.

'HYSTERETIC HO-DOWN'

Oh the Loaders and the Jointers should be friends
 Yes the Loaders and the Jointers should be friends
 One group thinks about forces at points
 The other is obsessed with beam-column joints
 But that's no reason why they can't be friends.

Earthquake engineers should stick together
 Earthquake engineers should all be mates
 Conferences should continue between New Zealand
 China, Japan and United States.

The Jointers' life is full of moments and shear
 They are all extremely fond
 Of struts confinement and of bond...
 But their relation to the Loader's not too clear.

Oh the Loaders and the Jointers should be friends
 Yes the Loaders and the Jointers should be friends
 One group thinks about forces at points
 The other is obsessed with beam-column joints
 But that's no reason why they can't be friends.

Earthquake engineers should stick together
 Earthquake engineers should all be mates
 Conferences should continue between New Zealand
 China, Japan and United States.

The Loaders are such good and trusty citizens
 Who work hard to establish overall loads and drift
 You'll seldom see them conferring with the Jointers..
 It's no wonder that we have this potential rift.

Oh, the Loaders and Jointers should be friends
 Yes the Loaders and Jointers should be friends
 Loaders specify loads of course
 Jointers are left to deal with the force
 Surely now it's time to join the ends.

Earthquake engineers should stick together
 Earthquake engineers should all be mates
 Conferences should continue between New Zealand
 China, Japan and United States.