



SG-C

Session Report
REPORT OF SPECIAL THEME SESSION SG ON
"DUCTILITY EVALUATION AND DESIGN OF CONCRETE STRUCTURES
AND ELEMENTS"

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INTRODUCTION

It has been long since earthquake resistant design procedures on the basis of ductility concept were introduced in codes or proposed in countries. Therefore, it was felt important to critically examine the future direction of the earthquake resistant design of reinforced concrete structures.

The objective of the session was to discuss ductility design approaches for reinforced concrete, partially prestressed and prestressed concrete structures and structural elements. Emphasis is placed on the definition and evaluation of available limit of ductility, ductility enhancing methods and ductility design procedures. The session was divided into two major sub-themes; i.e., sub-theme 1: "Ductility evaluation and ductility enhancing methods for members and subassemblages", and sub-theme 2: "Design of structures based on ductility concept". The organizers of the sessions carefully reviewed approximately eighty abstracts on the theme, and selected 10 abstracts on sub-theme 1 and 5 abstracts on sub-theme 2. It was unfortunate that one paper on sub-theme 1 and two papers on sub-theme 2 were not presented in the session. It was decided that a state-of-the-art report should be presented on each sub-theme, separately. Sub-theme 1 session was held from 9:40 to 12:40 and sub-theme 2 session from 14:00 to 15:40, both on August 8 in Room B-1. Approximately 250 participants attended the two sessions.

This report is intended to record the operation of the session and to summarize comments and discussions during the sessions.

SUB-THEME SESSION 1

The session started at 9:40 am at Room B1 and ended at 12:40, chaired by Dr. W. Gene Corley of Construction Engineering Laboratory, U.S.A., and Professor Shiro Morita of Kyoto University, Japan. Professor Robert Park of University of Canterbury, New Zealand, presented a state-of-the-art report, entitled "Ductility Evaluation from Laboratory and Analytical Testing" for 30 minutes. Following three papers were presented using 10 minutes each:

- 1) H. Muguruma : "Curvature Ductility Design of Reinforced and Prestressed Concrete Members",
- 2) W. G. Corley: "Assessment of Different Transverse Reinforcement Details in Earthquake Environment" and
- 3) A. Sumi : "Experimental Study of Reinforced Concrete Beams and Columns

Laterally Confined by High Tensile Strength Shear Reinforcements".

The paper by J. Schlaich was not presented because of his absence.

After 20 minutes of discussion time, six papers were presented using 10 minutes each as follows;

- 1) S. M. Uzumeri: "Reinforced Concrete Elements Subjected to Reversed Shear",
- 2) F. Watanabe : "Shear Design of R/C Members to Meet Ductility Requirements",
- 3) M. Calvi : "Ductility Evaluation of Concrete Wall Panels",
- 4) H. Hiraishi : "Deformation Behavior of Shear Walls after Flexural Yielding",
- 5) N. M. Hawkins: "Unbonded Post-tensioned Ductile Moment Resistant Frames", and
- 6) B. Zhu : "Aseismic Capacity of Bonded and Unbonded Prestressed Concrete Frames".

Discussion was held for 25 minutes. The followings summarize the discussion.

a) Efficiency of Cross Ties with 90 Degree Hook

Professor S.A. Sheikh, University of Houston, U.S.A., pointed out in relation to the paper presented by Dr. W.G. Corley that the increase in ultimate strains of concrete in cyclic loading tests might be caused partially by creep during the loading and hence if the total time of loading is kept in constant in two specimens load deflection curves might show similar shape. He also reported insufficient performance of his column specimens using cross ties with a 90 degree hook under high axial load. Dr. W.G. Corley recommended the use of continuous rectangular reinforcement to avoid the anchorage failure of the cross tie.

Professor R. Park of University of Canterbury, New Zealand, suggested to limit the use of the cross tie with 90 degree hook only in members intended for a limited ductility or in a region away from the plastic hinge.

b) Definition of Yielding in Columns under High Axial Load

Professor S.A. Sheikh questioned Professor R. Park about the definition of the first yielding in a column subjected to high axial load, because the yielding of tensile reinforcement did not occur under such situation and because a clear break-point was not observed in the load-deflection curve. Therefore, he proposed to define the yielding point as a point of the first deviation from a regular elastic curve.

Professor R. Park described that the stiffness of the "equivalent" elasto-plastic system was taken to be the secant stiffness at 75 percent of the ultimate load in the initial loading curve and the yield deflection is automatically determined in the elasto-plastic system thus obtained, and commented that the proposed yield deflection by Professor Sheikh might be too small.

c) Use of Welded Wire Fabric in Shear Wall

Professor N. Hawkins of University of Washington, U.S.A., pointed out to Dr. M. Calvi that the fracture strain of welded wire fabric was rather small, especially under the bi-directional yielding which might occur in a shear wall. Dr. M. Calvi of University of Pavia, Italy, explained that Italian specification for quality-type welded wire fabric required 10 percent of uniform elongation to maintain good performance of the shear wall.

d) Shear Design Procedure to Meet Ductility Requirements

Professor M. Yamada of Kobe University, Japan, asked Professor F. Watanabe whether the proposed shear design procedure could be applied to a member with small shear span-to-depth ratio because the failure mode of the member was strongly influenced by the ratio. Professor F. Watanabe replied that the procedure proposed could be applied to members of any shear span-to-depth ratio because the procedure was to ensure the shear resisting mechanisms in the post yield zone after flexural yielding at the critical section. The concrete strut stress was limited in accordance with the required ductility so that the undesirable shear failure caused by crushing of concrete strut be prevented. (In reality, the effect of shear span-to-depth ratio has been considered in his proposed design procedure.)

e) Testing under Simulated Beam-column Joint Stresses

Professor T. Paulay of University of Canterbury, New Zealand, commented on the desirability of maintaining the shear reinforcement in a beam-column joint in an elastic stage to avoid a rapid deterioration of concrete resistance under reversed cyclic loading, and also the desirability of uniform shear flow in a beam-column joint. However, he pointed out that such uniform shear flow could not be attained in a beam-column joint because of the break down of bond action between beam longitudinal bars and surrounding concrete. Then he pointed out that the testing model at the University of Toronto impressed a uniform shear stress flow at the boundary of an element and that the model did not simulate an irregular stress distribution typically observed in a beam-column joint. Professor S.M. Uzumeri accepted the point, and added that the test would be continued to develop a reliable mathematical model of reinforced concrete panel elements applicable to a beam-column joint panel.

Professor B. Zhu of Tongji University, China, asked Professor S.M. Uzumeri about the rule of similitude used in the testing model. Professor S.M. Uzumeri answered that the rule of similitude was not followed in the test model, and commented that the test was intended to develop an experimental capability within all existing limitations.

Dr. T. Ichinose of Nagoya Institute of Technology, Japan, asked Professor S.M. Uzumeri if the reduction of concrete strength under bi-directional cyclic loading was observed larger than that under uni-axial loading. Professor S.M. Uzumeri described that an experimental program was under way at the University of Toronto on this problem using prismatic specimens, and expected that the test would answer the question. Professor S.M. Uzumeri added that the aim of his test was to study the behavior of a concrete element reinforced in two directions.

f) Effect of Transverse Beams on Exterior Joint Behavior

Professor R. Park pointed out for the presentation by Professor N. Hawkins that the joint of full-scale exterior beam-column subassemblage seemed to have remained largely intact since the transverse beams were not loaded. He also commented that the transverse beams might be loaded as well in a real earthquake. Professor N. Hawkins responded that the transverse beams of the full-scale specimen were not loaded because of the limitation of the loading systems, and reported that the transverse beams of the two-third scale specimens were loaded to a working stress level and some damage was developed.

g) Prestressed Concrete for Ductile Structures

Professor T.P. Tassios of National Technical University Athens, Greece, pointed out the necessity of good understanding on physical phenomena of ductility, and stressed that the prestressed concrete structure might show a good behavior during earthquakes if it was designed on the basis of rational methods recognizing the available limit of ductility. He praised a method proposed by

Professor H. Muguruma for logical use of prestressed concrete in earthquake resistant ductile frames.

Professor R. Park commented that the nonlinear earthquake response analyses of single-degree-of-freedom systems with different hysteresis shapes representing reinforced concrete, partially prestressed concrete and prestressed concrete structures clearly showed response amplitudes of prestressed concrete models being larger 30 % than that of the equivalent reinforced concrete models due to the less hysteretic energy dissipation. However, the prestressed concrete structure could be made earthquake resistant simply by increasing lateral load resistance or by providing ductility. He stated that the prestressed concrete structures have been unduly penalized in the past because of the small energy dissipating capacity.

This discussion point was continued by Professor N. Hawkins. He showed another way that it can be realized by trying the use of the prestressed concrete in a relatively low level of prestressing force which is comparable to the low axial load reinforced concrete columns. Therefore, it is not necessary to increase the design seismic load because if the prestressing force induced to the structure is limited in relatively low level it can behave in almost same manner of reinforced concrete and the plastic hinge length do not change markedly. Professor N. Hawkins also introduced the development of a reliable analytical model, and suggested that the results of parametric studies using such reliable models would be placed into building seismic safety provisions for prestressed concrete.

SUB-THEME SESSION 2

The session started at 14:00 am at Room B1 and ended at 15:35, chaired by Professor Peter Fajfar of the University of Ljubljana, Yugoslavia, and Dr. Shin Okamoto of Building Research Institute, Japan. Professor Vitelmo V. Bertero of the University of California at Berkeley, U.S.A., presented a state-of-the-art report, entitled "Ductility Based Structural Design" for 30 minutes. Following three papers were presented using 10 minutes each:

- 1) T. Paulay : "Seismic Design in Reinforced Concrete, The State of the Art in New Zealand",
- 2) S. Otani : "Moment Redistribution in Earthquake Resistant Design of Reinforced Concrete Frames" and
- 3) T. Kabeyasawa: "Evaluation of Column and Wall Actions in the Ultimate-State Design of Reinforced Concrete Structures".

Two papers by Dr. A. Cismigiu and Dr. L. Huang were not presented because of their absence. The followings summarize the discussion.

a) Design Load Reduction Factors

Professor A.W. Sadek from Cairo University, Egypt, asked Professor V.V. Bertero if the design load reduction factor should be of a function of structural periods. Professor V.V. Bertero answered that the design load reduction factor should vary with a structural period and pointed out that the design load should not be reduced in a short period range for ductility. However, he also stated a possible over-strength of low-rise structures because of the non-seismic requirements.

Professor R. Park of University of Canterbury, New Zealand, introduced a structural ductility ratio concept used in coming New Zealand Loading Code, in which a design load reduction factor was period dependent.

b) Ductility Design and Code

Professor T.P. Tassios of National Technical University Athens, Greece, asked Professor V.V. Bertero about the requirements additional to the design load reduction spectrum by ductility to complete the ductility design philosophy. Professor V.V. Bertero stated that the ductility ratio was widely accepted as a simple index, but that there has been no agreement about its definition and realistic values since the concept was first applied to a realistic structural model because the ductility ratio was originally developed for an idealized elasto-plastic mathematical model. He stressed that the structures in each country must be carefully analyzed and calibrated to determine acceptable values of ductility ratios.

Professor R. Park pointed out a bright side of the ductility concept by saying that many experimental researchers started to use common definitions of a yielding point and an ultimate point. He stressed the importance of using the same definitions among experimental researchers and response analysts.

c) Number of Yield Excursion during Earthquake

Professor R. Park questioned Professor V.V. Bertero about the number of yield reversals during an earthquake, and pointed out that the number well over 60, quoted in the presentation, was not realistic for use in the laboratory test.

Professor V.V. Bertero described that the number 60 was obtained by a response analysis of a model designed in accordance with the existing code subjected to the 1985 Chilean Earthquake record. He pointed out that buildings might be designed to barely meet the code requirements due to economical pressure and in such case a large yielding excursion might take place as many as 13 cycles above ductility ratio greater than 4.0. However, he also stated that this kind of large ductility demand might not be necessary in California because the low-rise buildings often were provided with lateral load resistance significantly larger than the seismic code requires.

Professor T. Paulay of University of Canterbury, New Zealand, stated that a ductility factor was a simple and useful index to quantify the deformability of a structure, and that ductility could be easily attained by providing some extra lateral reinforcement without demanding a sizable increase in construction cost as long as the expected deformation was set within a realistic limit.

Professor S.M. Uzumeri of University of Toronto, Canada, pointed out the danger of studying the numerical values of single parameter without investigating the combined influence of all parameters on the structural performance, and also pointed out the importance of performance of a structure as designed.

d) Effective Width of Slabs Contributing to Beam Flexural Resistance

Professor A.C. Heidebrecht of MacMaster University, Canada, asked Professor T. Paulay how to estimate the overstrength of a beam monolithically cast with slabs in the capacity design procedure to ensure the beam hinging. Professor T. Paulay accepted the fact that the slab reinforcement would contribute to the beam flexural resistance, and that the more slab bars away from the beam would be mobilized as the deformation increased. However, he pointed out that the increase in resistance might not be significant, although he agreed the necessity of making an effort toward the honest estimate of the amount of slab reinforcement to participate in the resistance.

Professor S. Otani of University of Tokyo, Japan, introduced a draft guideline based on ultimate strength design, prepared by Architectural Institute of Japan, and described that the overstrength by strain hardening of beam

longitudinal bars and by spread of slab reinforcement contributing to beam flexural resistance was judged small because the expected inelastic deformation was small attributable to large design earthquake load in Japan.

e) Response of Short-period and Long-period Structures

Professor P. Fajfar pointed out on the basis of his experience on response analyses that the response of a short-period system and a long-period system is quite different. Short-period structures must be carefully designed to meet a large ductility demand.

CONCLUDING REMARKS by H. Muguruma

The session was proposed to the Special Theme Sessions Coordinator Council and planned by three coordinators: Fumio Watanabe of Kyoto University, Shunsuke Otani of the University of Tokyo, and Hiroshi Muguruma of Kyoto University. The session was intended for in-depth discussion on the ductility design approaches of reinforced concrete, partially prestressed concrete and prestressed concrete structures and structural elements, as well as to explore the future advancement and direction for ductility based design. Papers presented here were carefully selected from more than eighty excellent abstracts.

On sub-theme 1 entitled "Evaluation and Enhancement of Member Ductility", many different methods and concepts were presented. Excellent papers were presented on member ductility, but it became clear that more problems need be solved. On sub-theme 2 entitled "Ductility Based Structural Design", the design philosophies of ductile moment resisting frames were presented. Further exchange of information and discussion was felt necessary with the cooperation of researchers from different countries. The valuable discussion will be summarized and recorded in a proceeding volume on the Special Theme Sessions.

It is not possible to summarize the discussion of the session in a few words, but we sincerely hope that the session has been meaningful and rewarding to all participants, and that the session would initiate a new and creative development for research with a cooperation among engineers and researchers all over the world.

Finally, I would like to thank various people who contributed to the success of the session. Chairmen of the session: Dr. W. Gene Corley, Professor Shiro Morita, Professor Peter Fajfar, and Dr. Shin Okamoto, who operated the session in firm and efficient manner. Two eminent state-of-the-art reporters: Professor Robert Park and Professor Vitelmo V. Bertero. Twelve speakers who presented excellent papers. And the participants who actively participated stimulating discussion. We all want to thank you.