Wind and Seismic Effects

Proceedings of the 30th Joint Meeting

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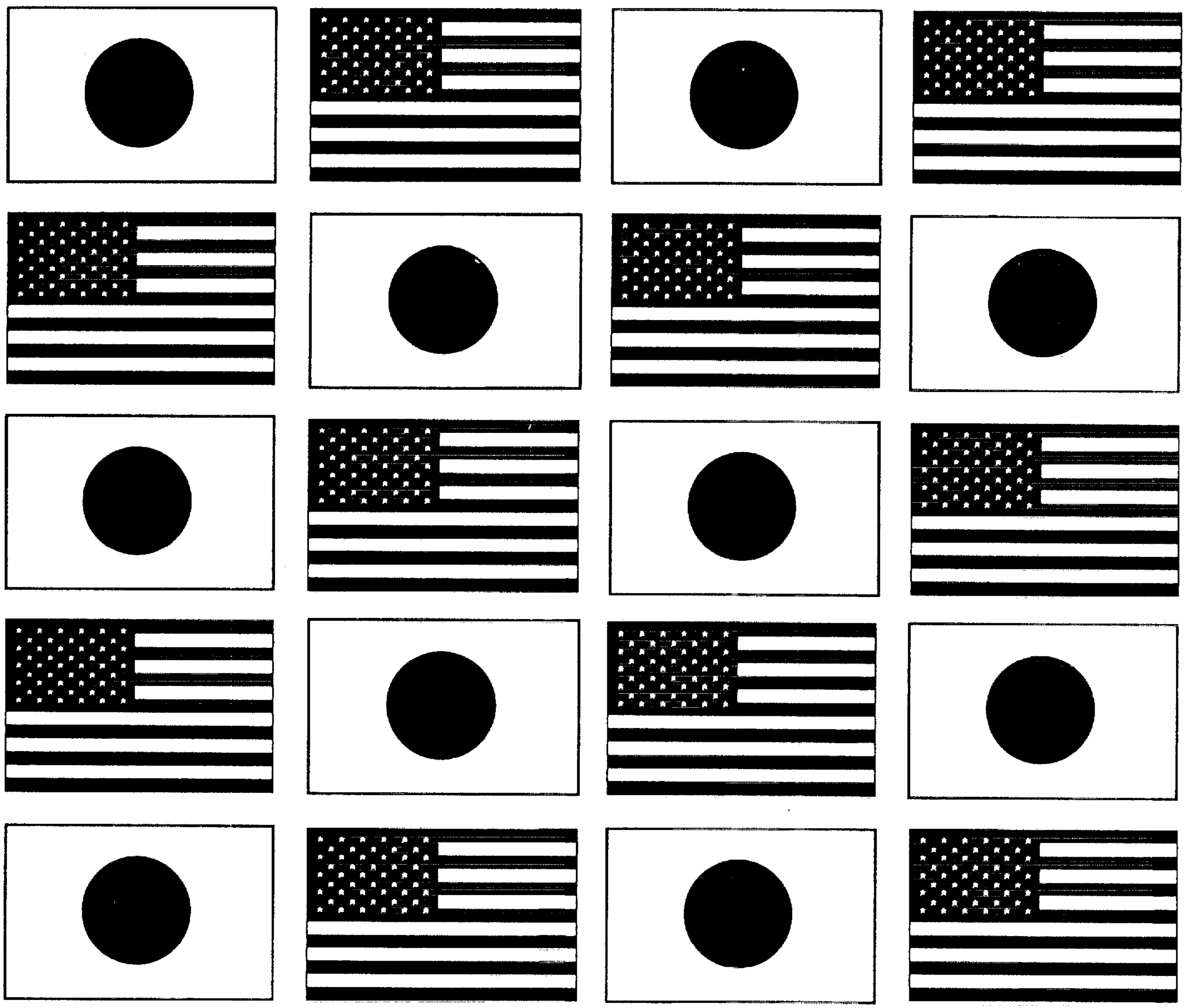

U.S. DEPARTMENT OF COMMERCE
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Wind and Seismic Effects

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PROCEEDINGS OF THE 30TH JOINT MEETING OF THE U.S.-JAPAN COOPERATIVE PROGRAM IN NATURAL RESOURCES PANEL ON WIND AND SEISMIC EFFECTS

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EARTHQUAKE ENGINEERING

Development of an Analysis of Structural Steel Fracture and Development of Technical Solutions

by
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ABSTRACT

This paper presents the outline of a comprehensive technology development project by the Ministry of Construction, Japan, in which an analysis of structural steel fracture and technical solutions should be developed. Material properties and welding effects on steel fracture, fabricating and fracture of connections and collapse mechanism and fracture of steel structures are now being investigated.

Key Words: Steel Fracture
Material properties
Welding
Collapse mechanism

1. INTRODUCTION

In the extremely strong earthquake that struck Kobe and other parts of southern Hyogo Prefecture on January 17, 1995, structural steel in high-rise buildings and elsewhere was found to have snapped like sticks of chalk.

Presently, the approach to construction of buildings and other structures using steel materials has two facets: elastic design to resist ordinary loads and small or medium-strength earthquakes by ensuring that no residual deformation will result from small-to-medium stresses to structural steel; and plastic design to ensure that in the event of a major earthquake, inelastic deformation of structural steel will dissipate enough energy to prevent the entire structure's collapse.

In the Kobe earthquake, however, structural steel materials broke before they could dissipate energy through inelastic deformation, suggesting that a force smaller than the design force was able to destroy them.

This is why studies will analyze these phenomena and devise ways to analyze, investigate, and develop effective remedies.

This project initiated in April,1996 and will be finished in March, 1999. In this project, Building Research Institute (BRI) is responsible for organizing and implementing the development of the analysis and solutions of steel members, welding and building structures.

2. FINAL GOAL

Our final goals are to clarify the demand for structural steel, to develop the guideline on welding procedures and to propose the design method for avoiding the brittle fracture of steel structures.

3. ORGANIZATION

BRI is carrying out the project as a cooperative research with The Kozai Club (KC). We have three sub-committees as shown in Fig.1. In addition, we are carrying out Research for Innovation(RFI) and US-Japan Cooperative Research as part of this project. In the following chapters, the outline of these activities will be introduced.

4. WELDING AND FRACTURE OF MATERIALS

In this sub-committee, five subjects are

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3) Research Engineer of Structural Dynamics Division, ditto

being investigated to clarify the material properties and welding effects on steel fracture. Those subjects are as follows:

(1) Effect of Size

Experimental variables are plate thickness (25mm, 40mm, 100mm) and toughness of steel plates (low toughness, high toughness).

(2) Effect of welding

Experimental variables are heat input (CO_2: 40 kJ/cm, ES: 800 kJ/cm) and toughness of steel plates (low toughness, high toughness).

(3) Effect of Impact

Experimental variable is loading rates (Static, 1 m/sec, 3 m/sec, 10 m/sec).

(4) Effect of Amplitude

Experimental variable is displacement amplitudes (monotonic, $\pm 2\delta_p$, $\pm 4\delta_p$, $\pm 8\delta_p$).

(5) Effect of Time

Experimental variable is the time of load duration (10 seconds, 5 minutes, 2.5 hours).

These subjects have been examined by beam bending tests; experiments with low toughness steel are almost completed.

5. FABRICATING AND FRACTURE OF CONNECTIONS

The objectives of this sub-committee are to analyze the factors of brittle fracture observed in the welded connection and to verify reliable measures for the new-generation steel, the fabrication procedures, in-process inspection of the construction of new buildings. The final goals of this sub-committee are to clarify the phenomenon of beam-to-column connections, truss connections, etc., to develop guidelines on the fabrication procedures for improving the seismic performance, to assess the economic, social and political costs of implementing the recommendations in details of connections for more reliable inelastic action and to revise AIJ's Standard for the Ultrasonic Inspection of Weld Defects in Steel Structures. There are four working groups in this sub-committee.

(1) Data Analysis

In this working group, to investigate the steel properties for building structures, fracture data base is under construction.

(2) Fundamental Study

In order to evaluate the material properties of steels prepared for full scale tests and to study the welding effects on material properties, material tests were conducted. Those were tensile tests, hardness tests, charpy impact tests, fracture toughness tests, etc.

(3) Full Scale Connection Test

To investigate the relationship between the plastic deformation capacity of beam-to-column connection and the toughness of materials/connection details/fabrication level, cyclic loading tests of beam-to-column connection have been conducted. The parameters are toughness of steel materials (low toughness/high toughness), connection details (conventional type/revised type), welding condition (normal heat input/high heat input), loading speed (static/dynamic) and slab contribution.

(4) Strain Rate/ Weld Defects Test

Butt welded joints and T weld joints with low toughness steel have been tested, to investigate the strain rate and weld defects on the strength/fracture of beam-to-column connection.

6. COLLAPSE MECHANISM AND FRACTURE OF STEEL FRAMES

The main objective of this sub-committee is to determine the required plastic deformation capacity of members in steel rigid frames subjected to earthquakes. It is presumed that the required plastic deformation capacity of steel members depends on the ultimate resistance of the frames, the formation of mechanism, the intensity of the input earthquake ground motions, and so on. In order to accomplish this objective, the following studies are now well underway in this subcommittee.

(1) Earthquake response analysis of the frames having brittle fracture at beam-ends

The earthquake response analyses of the 9-story 3-bay planar frame with brittle fracture were performed in order to investigate the effect of brittle fractures at beam-ends on seismic response of steel rigid frames.

Fig 2 shows the hysteresis model of plastic hinges at beam-ends assumed in the analysis model. The most important parameter of this analysis is the plastic rotation capacity (θ_F) of the hinges. In this model frame, the plastic rotation capacity (θ_F) of the hinges at beam-ends was assumed to be 0, 0.005, 0.01, 0.02rad.. Fig 3 demonstrates an example of the analysis results in terms of maximum interstory drift angles in each story. In case of $\theta_F = 0.01$, the maximum interstory drift angle of the frame against the Kobe earthquake ground motion is larger than that against the other earthquake ground motions.

(2) Simplified Response Prediction Models

In this sub-committee, the simplified fish bone model were developed to predict the seismic behavior of the frames. The predictions by using the fish bone model were compared to the results by using the frame model for verifying the predictability of the fish bone model.

(3) Column Overdesign Factor (COF) for Ensuring Beam-Collapse Mechanism in Earthquake Response

The objectives of this analysis is as follows;
1) To determine the COF needed for ensuring beam-collapse mechanism
2) To investigate plastic rotation expected to columns if the COF smaller than 1

From the results of the earthquake response analysis using the fish bone model, following the results were obtained.
1) Even if column yielding is permitted, overall behavior (including max. overall drift angle, max. story drift angle, max. beam rotation) remains relatively unchanged as long as the COF$\geqq$1.1.
2) For the case where the max. velocity of input EQ is 0.5 m/sec, max. column plastic rotation was smaller than 0.01rad. (3-story model) and 0.005rad. (6 and 9 story models) when the COF$\geqq$1.1.

(4) Experimental Study on Inelastic Behavior of Joint Panel Zone

This study was conducted to investigate the elastic-plastic behavior of joint panel zone and to propose the adequate guide on strength and rigidity. The following three series of tests were carried out in this study.
Series 1: Test on the beam to SHS (square hollow section) column connections subjected to diagonal bending moment (see Fig. 4)
Series 2: Test on the effect of manufacturing process of SHS column
Series 3: Test on the H-shaped column connections

(5) Model Building Studies

The objectives of this study is to investigate the seismic performance of U.S. steel perimeter frames and Japanese spatial moment resisting frames. For this purpose, the SAC theme structures have been redesigned by Japanese seismic code under similar soil and hazard conditions as spatial moment resisting frames using box columns.

A comparison between nonlinear responses of U.S. perimeter(SAC3-LA) and of redesigned Japanese spatial moment resisting frames(BRI3A, BRI3B) is performed. From the results of the earthquake response analysis, a clear difference in seismic performance of U.S. frames and Japanese frames in terms of interstory drift angles, cumulative plastic rotations($\eta_{\pm}$) was found. (see Table1, Fig. 5, Fig.6 and Fig.7)

7. RESEARCH FOR INNOVATION

We have just started the research on the new generation steel, new connection, new inspection and new structural system to create the new steel structural system.

8. US-JAPAN WORKSHOP

US-Japan workshops on steel fracture issues were held three times. The first workshop was held in June, 1996 in San Francisco and UC Berkeley. The second one was in February, 1997 in San Francisco. And the third one was in April ,1998 in Tokyo. In those workshops, the information on the research results was exchanged between both countries and future cooperative research items were discussed. The proceedings of the first two workshops have been available, (Ref.1) (Ref.2).

9. CONCLUSION

The outline of the project on the steel fracture issues was presented. It is hoped to complete our project with practical recommendations in the next year.

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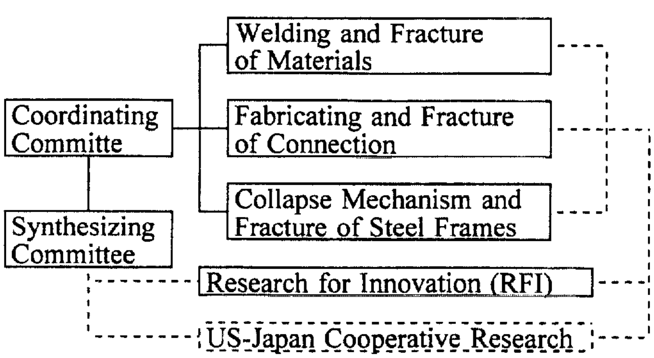

Fig.1 Organization

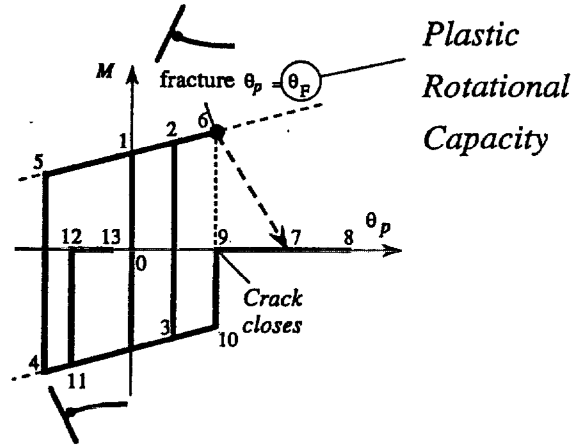

Fig.2 Hysteresis Model of Plastic Hinges at Beam-ends

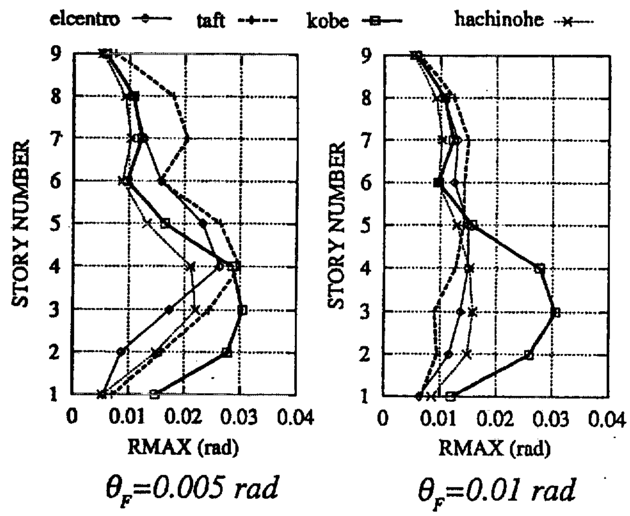

Fig.3 Maximum Interstory Drift Angles

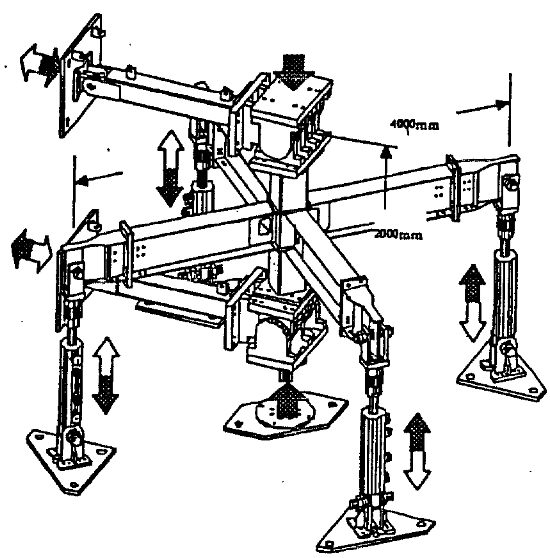

Fig.4 Diagonal Loading Test

Table 1 Beam and Column Sections of 3-Story Frames

Story/Floor	BRI3-A			BRI3-B			SAC3-LA		
	Column (BCR295)		Girder (SN400B)	Column (BCR295)		Girder (SN400B)	Column (50ksi)		Girder (36ksi)
	Ext.	Int.		Ext.	Int.		Ext.	Int.	
3/4	□-450×16		H-550×200×9×19	□-400×16		H-550×200×9×16	W14×257 (H-419×407×31×49)	W14×311 (H-437×412×36×58)	W24×68 (H-602×228×11×15)
2/3	□-450×19			□-400×19		H-550×200×9×19			W30×116 (H-762×267×14×22)
1/2	□-450×22		H-550×200×12×22	□-400×22		H-550×200×9×22			W33×118 (H-835×292×14×19)

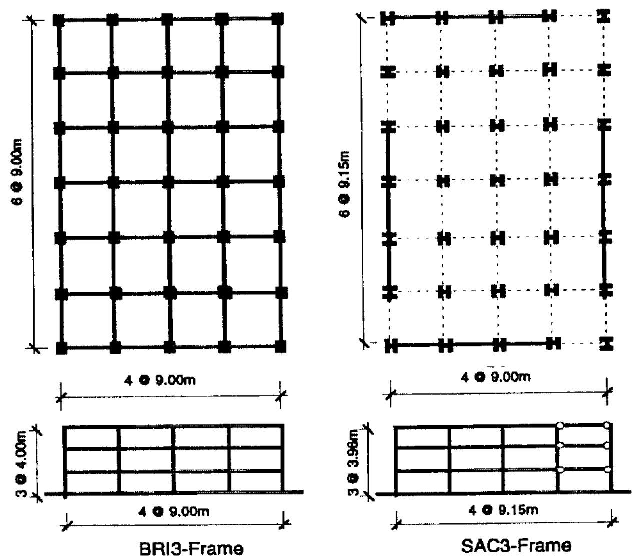

Fig.5 Plan Views and Elevations of 3-Story Frames

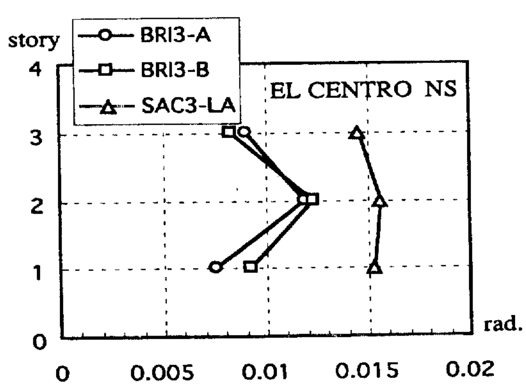

Fig.6 Maximum Interstory Drift Angles (Vt=150kine)

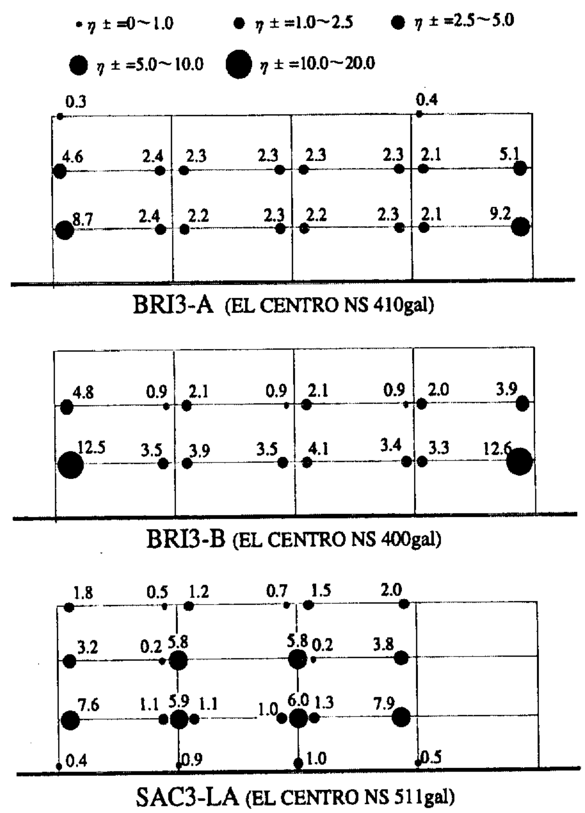

Fig.7 Damage Distribution (Vt=150kine)