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Damage Control Design Based on Hysterisis Damping Effect

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Summary

Recently, in Japan, remarkable progress has been made in the field of structural response control, after the Hanshin-Awaji Earthquake of 1995 caused many steel structure buildings to fail. This paper reports on the design of a 15-story steel structure building employing two types of hysteretic damper systems. One is composed of a steel bearing wall skirted by boundary beams on either side. The other is composed of a boundary beam passing between two braced mega-columns. In the case of a big earthquake, these boundary beams work as hysteretic dampers through plastic deformation, thereby preventing damage to the main beams and columns bearing vertical loads.

1. Structure Design

1. 1 Outline of Structure

The building reported on in this paper is an office building with a 15-story steel structure. The perspective drawing of the building is shown in figure 1. The plan of a typical floor of the building is a rectangle spanning 37.8 by 23.6 meters. The height of the building is 59.3 meters. The plan and section of the building are shown in figure 2 and figure 3. The basic structural system of the building above ground is a moment frame with damper system.

figure 1 A perspective drawing of the building

1. 2 The mechanism of the damper system

Two types of hysteretic damper systems are applied in the structural design. One consists of the combination of steel shear walls and boundary beams. Henceforth this system will be referred to as the shear wall type. The other consists of the combination of braced mega-columns and boundary beams, and will henceforth be referred to as the brace type.

The shear wall type is made of a steel plate with boundary beams on both sides. The design concept is for the boundary beams to behave as dampers, absorbing seismic energy mainly through plastic deformation in the web, as a result of shear stress. Therefore the web plate is made of low yeild-point steel (LYP235 has a yield strength of about 235 MPa). LYP235 exhibits little deviation of yield strength and good elongation. The architectural advantage of this system is that it allows floor to ceiling openings between boundary beams on both sides of the shear wall.

The brace type is composed of a boundary beam passing between two braced mega-columns, each mega column being composed of two columns joined by cross bracing. In this system the boundary beams dissippate seismic energy mainly through plastic deformation of the flange plates, as a result of bending moment. These beams are made of normal steel material (SM490A, which has a yield strength of about 330 MPa). The design advantage of this system is that floor to ceiling openings can be arranged between boundary beams.

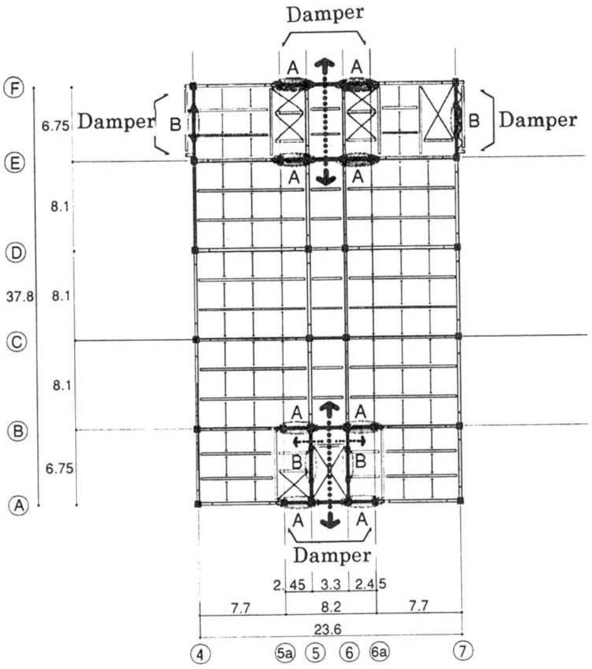


figure 2 The plan of the building

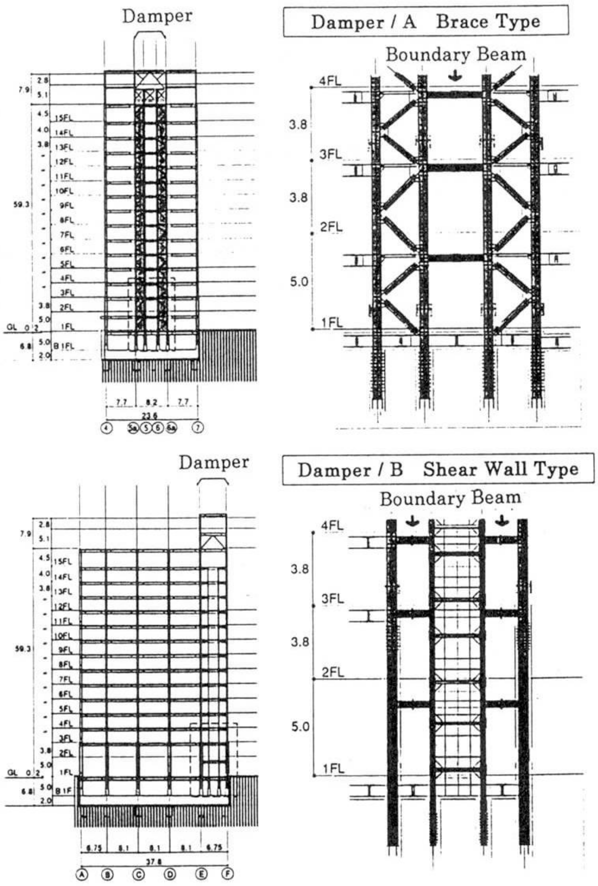


figure 3 The section of the building

1. 3 Strctural Design Concept

The building is designed according to Japanese architectural standards. In the case of a big earthquake, the boundary beams will work as the hysteretic damper through plastic deformation, thereby preventing damage to main structural members bearing vertical loads. The damper resists about 10% to 50% of the seismic force (average about 30%) at each floor. The target structural performance is shown below.

Table-1 The target structural performance

		Level I (25 cm/s)	Level II (50 cm/s)
Slope by relative storey displacement		under 1/ 200	under 1/ 100
Ductility factor of a general beam		Elastic	under 4.0
Ductility factor of a boundary beam	Shear yield type	Elastic	under 20.0
	Bending yield type	Elastic	under 4.0
Column・brace steel plate shear wall		Elastic	Elastic

2. Inspection of Damper Effect by Dynamic Analysis

2. 1 Static Elasto-Pastic Analysis

Static elasto-plastic analysis was carried out with a plane frame model. The skeleton curve of each story is modeled on a tri-linear curve as defined below. The upper limit of resistance force at each story is defined through the method of virtual work. The hysteresis characteristic was modeled to Normal Tri-Linear type.

First bending point: point at which any beam at a given story first yields

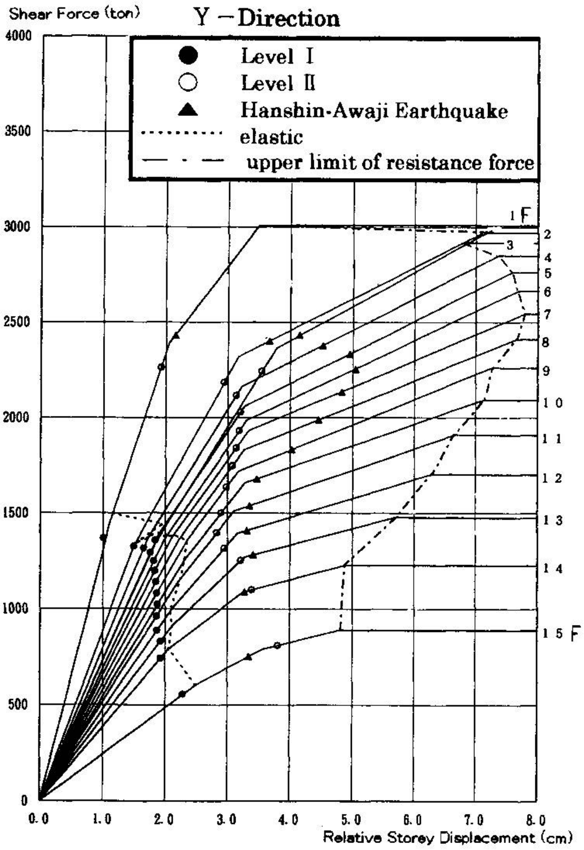
Second bending point: point at which half of the beams at a given story yield

2. 2 Dynamic Analysis

The response analysis was performed in the cases of the following earthquakes: El Centro 1945 NS, Taft 1952 EW, and Hachinohe 1968 NS, each on both level I (25 cm/s) and level II (50 cm/s). Furthermore, the seismic wave (with a maximum velocity of 85 cm/s) observed during the Hanshin-Awaji Earthquake in 1995 was input for the simulation. The seismic wave was recorded at the NTT Kobe Building (B3F) located in front of the JR Kobe Station. The first natural period of the building studied in this report is 1.95 seconds in both directions. The result of response analysis is shown in table 2 and figure 4. The plastic hinges which occured in the building during simulation of the Hanshin-Awaji Earthquake are shown in figure 5. The maximum ductility factor is 2.70 for main beams, 11.5 for boundary beams of shear wall type, and 4.20 for boundary beams of brace type. It is confirmed that the structure satisfies the target performance through these analyses. The ductility factor of the typical main beam is smaller than that of a boundary beam.

Table-2 result of earthquake response analysis

		Level I (25 cm/s)	Level II (50 cm/s)	Hanshin-Awaji Earthquake (85 cm/s)
Slope by relative storey displacement		1/ 196	1/ 102	1/ 74
Ductility factor of a general beam		Elastic	2.05	2.70
Ductility factor of a boundary beam	Shear yield type	Elastic	7.80	11.5
	Bending yield type	Elastic	2.95	4.20
Column・brace steel plate shear wall		Elastic	Elastic	Elastic



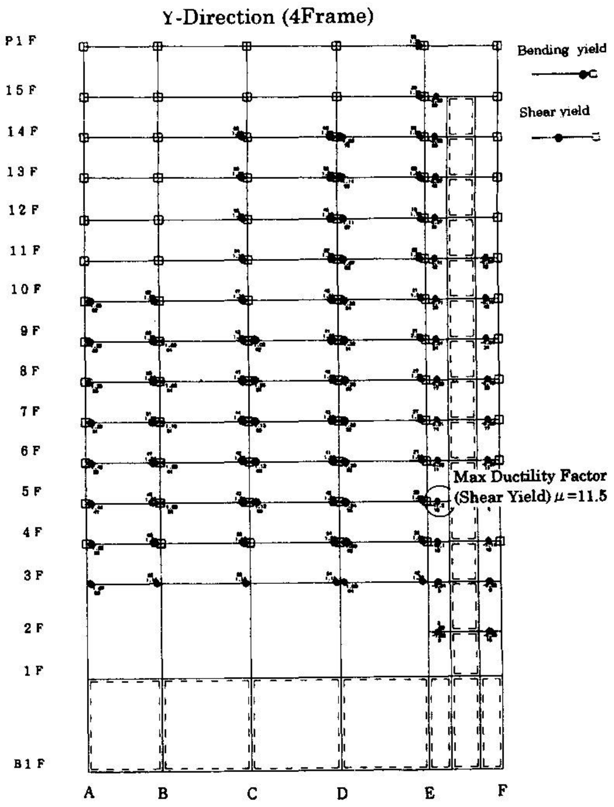


figure 4 Skeleton curve and Result of response analysis

figure 5 The plastic hinges in the building (Hanshin-Awaji Earthquake)

2. 3 Evaluation of Damping Effect

The total dissipated seismic energy is broken down into viscous damping energy, hysteretic damping energy of damper, and kinematic energy, in order to evaluate the damper's performance.

In the case of the shear wall type damper (long span direction of the building), viscous damping is 2.0%, hysteretic damping of framework is 0.33%, and hysteretic damping of damper is 0.67%.

In the case of the brace type damper (short span direction of the building), viscous damping is 2.0%, hysteretic damping of framework is 0.20%, and hysteretic damping of damper is 0.53%.

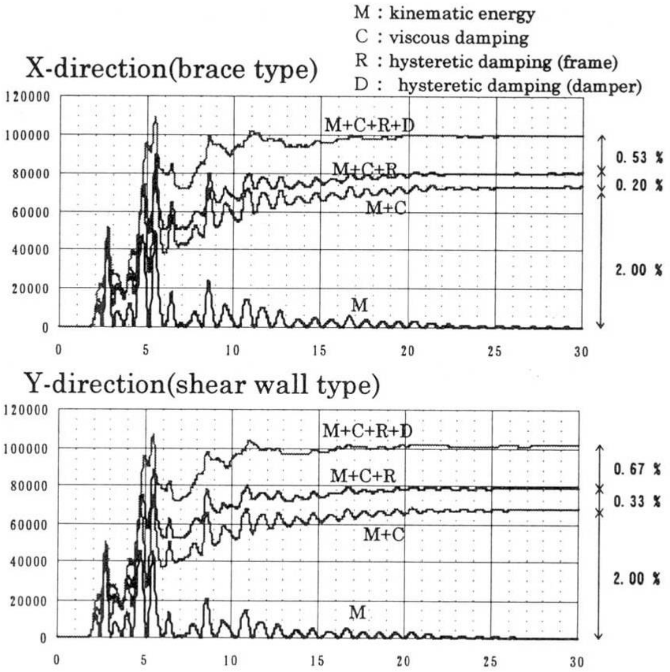
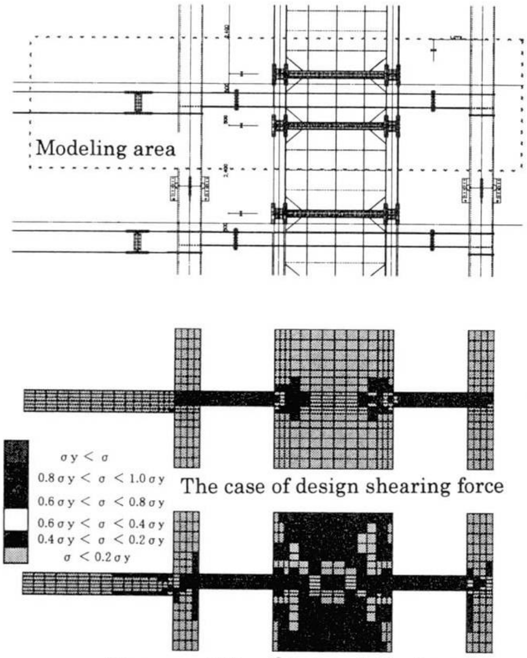


figure 6 Evaluation of Damping Effect

2. 4 FEM Analysis of steel plate shear wall and boundary beam

An FEM analysis of the shear wall system was used to minutely evaluate the stress condition of boundary beams in a state of maximal deformation. Von Mieses stresses for the case of design shearing force and the Hanshin-Awaji Earthquake, respectively, are shown in figure 7. Each member is elastic in the case of design shearing force. The boundary beams yield entirely in the case of the Hanshin-Awaji Earthquake.



The case of design shearing force

The case of Hanshin-Awaji Earthquake

figure 7 Result of FEM analysis

3. Conclusion

In general, it is difficult to arrange braces or shear walls in a structural design because they put restriction on the floor plan or to natural lighting. The damper systems presented in this paper are, however, of significant advantage to architectural performance, because they can be placed so that openings will accomodate the requirements of a given floor plan. This flexiblility makes these systems widely applicable in the realm of structural response control.

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